INCREASING FISSILE INVENTORY ASSURANCE WITHIN THE U.S. DEPARTMENT OF ENERGY

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The study compared the IAEA's approach to NDA to the approach used in the DOE. The IAEA has standardized measurement methods and data analysis software. The IAEA equipment is similar to the DOE equipment, although it has wider applicability because of the development of specialized detectors (such as fuel bundle collars). The IAEA does not use calorimetry, and the AWCC has had only minimal use in IAEA field measurements because of the limited quantities of metal outside the United States and the former Soviet Union. The AWCC is currently being field tested in the United States, as well as version of the AWCC using multiplicity counting.

Although NDA is used both nationally and internationally, the requirements for obtaining accountability values are different. Nationally, DOE orders require that each facility have an accountability measurement method for all nuclear material on inventory, including special nuclear material in receipts. When processing operations are suspended, the capability to obtain samples and perform destructive analysis is limited and NDA becomes the preferred method. When the requirement, as is the case for the IAEA, is to independently verify the facility's nuclear material inventory values, the advantage of NDA to compare items rapidly and accurately dictates the need for NDA. When NDA is supplemented by the destructive analysis of a sample from a group of items, the accuracy, precision, and traceability of the destructive analysis measurement can be extended to all items, thereby reducing the uncertainty of the independent determination. This approach is proven and is preferable for international inspections.

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EXECUTIVE SUMMARY

This study analyzed the status of and outlook for the Department of Energy's measurement program for its inventory of plutonium and high enriched uranium.

The Department of Energy (DOE) Office of the Deputy Assistant Secretary for Security Evaluations conducted a special study of DOE's inventory of plutonium and high enriched uranium, with emphasis on measurement systems. The purpose of the study was to analyze the status of the inventory and measurements program, identify areas of concern, and identify where these concerns can be addressed in a cost-effective manner. Some of the factors that prompted Security Evaluations to conduct the study included plans to open DOE facilities to bilateral and International Atomic Energy Agency (IAEA) inspections, the changing mission of many DOE facilities from production to environmental restoration, and weaknesses noted during inspections. To assure consistency with DOE's objectives and other ongoing efforts, the study was conducted in coordination with the DOE Nuclear Materials Disposition Project Office, and was supported by the DOE Offices of Security Affairs, Defense Programs, and Environmental Management.

Inaccuracies in nuclear material measurements, coupled with significant quantities of unmeasured scrap, pose a formidable problem for the Department as it prepares for long-term material storage, environmental restoration, and international inspections.

Many of the values in DOE inventory records are based on inaccurate measurements, are estimated, or cannot be defended because of lack of appropriate records. The magnitude of the problem is significant. DOE currently possesses approximately 10,000 kg of plutonium scrap and nearly 100,000 kg of high enriched uranium scrap, representing about 10 percent of the special nuclear material inventory. Accurate values do not exist for most of this scrap, and the amount of scrap will increase. In addition, there have been large inventory differences, most of which stem from the early years of the weapons program, when the inventory values were based on inaccurate measurement techniques and equipment, or estimates. Now that production operations have essentially ceased across the complex, DOE faces a formidable challenge in attempting to improve the accuracy and defensibility of its inventory values in preparation for long-term storage, environmental restoration activities, and international inspections.

Current measurement technology is sufficient to perform many of the necessary measurements.

Advances in measurement technology and techniques have greatly increased the capabilities for accurate special nuclear materials measurements. With current technology, it is now possible to measure many types of scrap and impure materials at DOE facilities. Even at facilities that now have suitable equipment, much material has been in storage for extended periods and has not been measured since suitable equipment was obtained.

Although physical security measures and material control mitigate identified weaknesses in material measurements, an accurate inventory is necessary for continued assurance against theft or diversion.

Although the accuracy of the inventory is less than desired, the risk of theft or diversion of strategic quantities of special nuclear material is low at most DOE facilities because of the other controls in place (e.g., physical security measures and material controls). In addition, there are relatively few opportunities for theft and diversion since weapons production operations have ceased and nearly all of DOE's special nuclear materials inventory is in static storage. Further, recent events such as those in Germany involving Russian plutonium indicate that groups interested in obtaining special nuclear material appear to be more likely to attempt to obtain it through easier means than stealing it from DOE facilities. However, an accurate inventory of special nuclear materials is necessary to provide assurance that material has not been stolen or diverted. In some instances, the inventory and measurement programs do not provide reliable information.

Holdup)material remaining in process equipment and piping)represents a unique safeguards concern, requiring more accurate accounting as physical security and material controls are decreased.

Holdup (material contained in process equipment or piping and that is not easily removed) represents a unique safeguards concern. Most of the holdup at DOE facilities has not been accurately measured, and some has not been measured at all. At some facilities, holdup is not reflected in the inventory records; in such cases, there is no mechanism for the accountability systems to detect theft or diversion of material in holdup. Accurately accounting for holdup is becoming increasingly important as decontamination and decommissioning efforts continue, while physical security measures are being removed to simplify access to facilities.

Accurate measurements will also facilitate international inspections of Departmental facilities and will enhance personnel and environmental safety.

In addition to protecting against theft and diversion, other factors provide an impetus to enhance the measurements program, including planned bilateral and IAEA inspections, and the need for accurate information about special nuclear materials to provide for personnel and environmental safety, criticality safety, and reduced radiation exposure during environmental restoration activities. In many cases, DOE does not have sufficiently accurate information on hand about its special nuclear materials inventories to fully support international activities, or to allow DOE facilities to properly plan for decontamination and decommissioning activities. Further, DOE's efforts to dispose of excess special nuclear material and clean up its weapons production facilities could be hampered by the lack of accurate information about the amount and types of material present in those facilities.

For each material type and site-specific situation, the expected benefits of enhancing the measurement program must be weighed against the costs.

Decisions on enhancing the measurement program must be made carefully, weighing the expected benefits against the costs for each type of material and site-specific situation. Measuring all materials that do not have accurate accountability values with today's accurate measurement equipment and techniques would be expensive and time-consuming, and involves hazards to workers (e.g., radiation exposure) that must be minimized. Additional inventory differences, both positive and negative, are inevitable as newer, more accurate measurements are compared with older values. Some types of materials will require processing to a more stable or measurable form before more accurate measurements are possible, and some facilities are not presently able to resume even limited processing.

For some materials and sites, long-term benefits will include reduced operational costs, improved safety, and lower potential for embarrassment.

Although there are no easy or quick solutions to problems that have grown over fifty years of operations, there are some actions that can be taken to enhance the program. Some of these actions can be implemented in the near term with little program impact or cost; others will require more time and resources but may have long-term benefits (reduced operational costs, improved safety, lower potential for embarrassment) that outweigh the costs.

A Department-wide program is necessary to ensure coordination, consistency, and cost effectiveness in decisions pertaining to enhanced safeguards measurements.

Enhancements in safeguards policy and guidance. While some facilities have already begun the work of obtaining accurate measurements for their materials, a comprehensive, DOE-wide program with Headquarters-level direction and guidance is needed to ensure coordination, consistency, and cost effectiveness across the complex. DOE Headquarters should provide guidance to the field on analyzing the costs and benefits of obtaining accurate measurement values for all of their materials, and should emphasize the need to conduct new measurements whenever the cost/benefit analyses show it to be feasible. Policies should be reviewed and developed as needed to reflect the measurements and inventory issues that will be encountered during bilateral and IAEA inspections at DOE facilities. The increase in processing and repackaging has focused attention on the need for policy governing remeasurements and on applying controls at facilities that may have holdup. Other potential policy and guidance enhancements include clarifying terminology (e.g., "difficult-to-measure"), resolving the nearly 400 open shipper/receiver transactions involving plutonium and high enriched uranium, and standardizing the composition-of-ending-inventory codes.

A steering group should be charged with establishing priorities to ensure that measurement equipment and trained personnel are available when and where needed.

Enhancements in the measurement program. One obstacle to measuring all the special nuclear material present at DOE facilities is the lack of equipment and trained personnel at some facilities. Measurement equipment, computer software, procedures, and training needed by some DOE sites are present at other sites and, with proper intersite and interagency coordination and support, may be adaptable or upgradable for their use. By providing underutilized equipment to sites that need it, it may be possible to avoid purchasing some components and thus save a portion of the total measurement costs. DOE Headquarters could coordinate the measurement needs of individual facilities with resources available at other facilities. The transfer of measurement equipment and personnel among DOE facilities would be facilitated by standardized training and measurement procedures; standardized measurement systems, containers, techniques, and software; and standards for nondestructive assay measurements. A steering group could be charged with establishing priorities for action and tracking and monitoring progress toward enhancing confidence in the inventory values across the complex.

Enhanced policy, more definitive guidance, and better coordination are key to success in increasing the Department's confidence in its nuclear material inventory values.

In summary, many aspects of the current measurements program have been enhanced in recent years but unmeasured material and holdup require additional attention. The lack of accurate inventory values places increased reliance on physical and material controls, which are being reduced due to budget constraints. Measurement equipment technology has advanced significantly in recent years, and it is now feasible to accurately quantify much of the special nuclear material at DOE facilities. Improved measurement programs will increase the confidence in the inventory values and provide a sound basis for international inspections and facility decontamination. However, additional measurements are costly and potentially hazardous; decisions to conduct them must be based on a careful analysis of the potential improvements in safeguards effectiveness, potential issues during international inspections, impact on worker health and safety, and the cost and availability of equipment. Enhanced policy, more definitive guidance, and better coordination are the key to assuring that such decisions are cost effective and reflect DOE priorities.

Increasing Fissile Inventory Assurance Within the U.S. Department of Energy

1.0 INTRODUCTION

At the direction of the Department of Energy (DOE) Deputy Assistant Secretary for Security Evaluations, a team of specialists in material control and accountability conducted a special study of DOE's inventory of plutonium and high enriched uranium, with emphasis on DOE's measurement systems and programs. The goals of the study were to analyze the status of the inventory, identify areas of concern, and identify aspects of the program that can be enhanced.

Longstanding weaknesses in measurement systems and inaccuracies in inventory values are no longer acceptable.

The DOE special nuclear material control and accountability community has long recognized that there are weaknesses in the special nuclear material accountability systems, most notably in measurement systems and the accuracy of the values in the special nuclear materials inventory records. Many of these weaknesses stem from the early years of the weapons program, when DOE generated large quantities of unique scrap materials as part of the weapons development and production efforts. This material was not processed because of the priority associated with producing weapons components, and inventory values were often based on estimates or on measurements made with inaccurate techniques and equipment. During the Cold War, the weaknesses in the special nuclear materials accounting systems were accepted because of the priority placed on production and the effectiveness of other protection measures, such as physical security systems. Figure 1 shows one example of materials generated during the years when production was the highest priority at DOE facilities and when providing defensible accountability values was a secondary consideration. Although most DOE special nuclear materials are stored in stable configurations in appropriate containers, there is some material, such as that shown in Figure 1, that is not in a suitable configuration for storage; the challenges associated with measuring such materials are considerable.

Accurate inventory records are needed to facilitate environmental restoration, nonproliferation, and international inspections.

With the end of the Cold War, DOE priorities are changing to increasingly emphasize environmental restoration and nonproliferation. Accurate special nuclear material inventory records are needed to assure adequate protection and safe handling and storage. Further, DOE facilities are becoming increasingly subject to international inspections, and DOE's inventory values for some types of material are not currently accurate enough to meet international standards. The lack of accurate and defensible inventory values could damage the United States' credibility in the international community, and could affect nonproliferation efforts. Now that DOE's production of special nuclear materials and weapons has essentially ceased, DOE

faces a formidable challenge in improving the accuracy and defensibility of its inventory values in preparation for long-term storage, environmental restoration, and international inspections.

This study identifies realistic, effective, and cost-efficient enhancements to the Department of Energy's programs for nuclear material measurements and accounting.

Some of the factors prompting this study are identified in Table 1; these factors are discussed in more detail in Appendix A. The purpose of this special study is not to criticize past decisions that led to the current situation, or to criticize any individual DOE element. In fact, many individual facilities and DOE Headquarters have taken proactive steps to address known problems. Rather, this study is forward-looking, focusing on actions DOE should take in light of changing priorities. To this end, the study systematically delineates the concerns and identifies a set of realistic, effective, and cost-efficient enhancements to promote long-term solutions. To assure consistency with DOE's objectives and other ongoing efforts, the study was conducted in coordination with the DOE Nuclear Materials Disposition Project Office, and was supported by the DOE Offices of Security Affairs, Defense Programs, and Environmental Management. Appendix B provides more detail about the conduct of the study and some key terminology.

The main body of the report is intended to provide managers with the key results, without unnecessary jargon. Following this introductory section, Section 2 provides an overview of the status of the DOE inventory of special nuclear materials, focusing on the accuracy of inventory values, inventory differences, and the DOE measurements program. Section 3 discusses the impacts of the recognized weaknesses in DOE's material accounting program and the incentives for improvement. Section 4 provides a more detailed discussion of areas that significantly affect inventory assurance, and identifies potential program enhancements. Section 5 describes a coordinated and systematic approach for prioritizing and conducting measurements that will lead to a higher level of assurance in inventory values. Section 6 summarizes the conclusions of the study and the potential enhancements. Detailed and supporting information is provided in a series of appendices.

Table 1. Factors Prompting the Special Study of the DOE Special Nuclear Materials Inventory

Security Evaluations findings have identified unmeasured inventories and measurement systems that are not in compliance with DOE orders.

The DOE openness initiative requires DOE to release information about its inventory of plutonium and high enriched uranium.

The existing quantity of special nuclear materials is excessive in relation to United States defense needs; planning is now under way for the ultimate disposition of this excess material, but in the interim it must be stored safely and securely.

Special nuclear materials will be made available for inspection by both the International Atomic Energy Agency and Russia.

A disposition team has been established to evaluate options for disposal of excess special nuclear materials and to provide assurance that materials are safe for interim and long-term storage.

Organizational responsibility for some existing DOE facilities and materials is being transferred from Defense Programs to Environmental Management.

Unmeasured/unaccounted for holdup of special nuclear materials is an operational concern at DOE facilities.

Policy changes are affecting the accountability of special nuclear materials.

Plutonium vulnerability assessment team activities may result in repackaging or limited processing of materials.

Remeasurement and/or measurement after limited processing of materials creates variations due to operating losses, inaccuracies in prior measurements, and inherent uncertainties in measurement methods.

DOE is experiencing reduced budgets and increased emphasis on cost-effective operations.

The special nuclear materials inventory is only one part of an integrated safeguards system; physical security measures are being reduced as a result of changing budgets and operational requirements.

2.0 STATUS OF DOE INVENTORY ASSURANCE

This section provides an overview of the status of the special nuclear materials inventory beginning with a discussion of the inventory) that is, the quantities and locations of special nuclear material in DOE's possession) and inventory differences and their causes. Next, the accuracy of inventory values is characterized. Finally, the status of measurement technology and DOE measurement programs is discussed, with emphasis on the capabilities of modern measurement technology to measure the types of materials of greatest concern to DOE.

2.1 Inventory and Inventory Differences

Although weapons production has ceased, decommissioning and weapons dismantlement will increase the inventory of special nuclear material.

The term "inventory" as used here refers to the quantity and locations of special nuclear material in DOE's possession. Since 1942, the United States has produced 90.6 metric tons of plutonium and 994 metric tons of high enriched uranium. The plutonium was produced in nuclear reactors at the Hanford Site (54.5 metric tons of weapons grade plutonium) and Savannah River Site (36.1 metric tons of weapons grade plutonium). The high enriched uranium was produced by enriching uranium using a gaseous diffusion process at the K-25 plant (483 metric tons) and Portsmouth (511 metric tons). Although DOE has not produced plutonium or high enriched uranium for a number of years, the DOE inventory of special nuclear material is increasing as nuclear weapons are returned to DOE for dismantlement as part of the nuclear weapons arsenal reduction.

The amount of scrap is also increasing.

As a result of weapons production and other processing activities, the high enriched uranium and plutonium are present in a wide variety of chemical forms, including pure metal (e.g., buttons), alloys, oxides, nitrates, and a variety of other forms. Further, the material is present in a wide variety of physical forms, including solids, solutions, and gases. The primary end products of the DOE special nuclear material processing operations are weapons components, reactor fuel, and miscellaneous components (e.g., critical assemblies). However, the processing activities result in significant quantities of process byproducts in a variety of forms, ranging from scrap metal to floor sweepings. Research and development activities are also responsible for the generation of unique scrap materials that will require special processing to a stable form for long-term storage. Further, with the current emphasis on decommissioning activities, DOE facilities are generating more scrap material, which is often difficult to measure.

Safely and securely storing surplus material is a complex-wide challenge.

Figures 2 and 3 show the current locations of the bulk of DOE plutonium and uranium, respectively (exclusive of classified quantities). As can be seen in these figures, the major plutonium inventories are located at Rocky Flats and Hanford. The major inventories of high enriched uranium are at Y-12, Savannah River, and Portsmouth. A large, though as yet undetermined, amount of this material is surplus to projected U.S. defense needs. One of DOE's greatest challenges is to develop methods to safely and securely store this material while determining which options will be selected for the ultimate disposition of excess special nuclear materials.

Inventory difference data were only recently declassified.

In addition to the amounts of material, Figures 2 and 3 show the cumulative inventory differences for the major production facilities in the DOE complex. The inventory difference data are also provided in Table 2. The plutonium inventory difference is twice as large as that for high enriched uranium, despite the fact that nearly ten times as much high enriched uranium has been produced. This results from the difficulties in measuring plutonium, poor estimates of plutonium production, and the additional processing steps required for plutonium. These values were declassified by the Secretary of Energy and presented during the Secretary's June 1994 press conference. Since then, the complicated topic of inventory differences has been the subject of much public interest and discussion. The term "inventory difference" refers to the adjustments to the inventory values that occur after a physical inventory is performed. Calculating inventory differences is conceptually simple, although the evaluations of inventory differences are complex. They are the difference between the amount of special nuclear material that the records indicate should be there, and the amount that is determined to actually be there when a physical inventory is conducted **)** that is, when the facility physically checks the items on hand.

Inventory differences are conceptually simple, although they involve complex calculations.

The process for determining inventory differences can be compared to counting money in the cash register at a supermarket. The cashier counts the money in the register at the beginning of each day (equivalent to the beginning book inventory). During the day, items are sold and returned, and all transactions are recorded on the cash register tape (equivalent to transferring special nuclear material to or from the material balance area account). At the end of the day, the transactions on the tape can be totaled to determine the amount of money that should be in the cash register (equivalent to the ending book inventory). Also at the end of the day, the money in the cash register is counted (equivalent to the physical inventory).

Figure 2. Plutonium Inventory and Inventory Differences

Figure 3. High Enriched Uranium Inventory and Inventory Differences

Just as a cash register tape shows how much money should be in the till, inventory records show how much material should be present during a physical inventory.

If the amount actually in the cash register at the end of the day is equal to the amount that the tape indicates should be there, there is no inventory difference and no reason for concern. However, there may be differences, either positive (less money/material in the register/physical inventory than the tape/book inventory indicates should be there) or negative (more money/material in the register/physical inventory than the tape/book inventory indicates should be there). These differences (inventory differences) need to be investigated. After the investigation is complete and the reasons for the differences explained, the books are updated and closed for that day (or accounting period). The process is then repeated the next day/accounting period.

Table 2. Cumulative Inventory Differences by Facility

Facility	Plutonium Inventory Difference (kg)	High Enriched Uranium Inventory Difference (kg)
Hanford	1,265	3
Rocky Flats	1,191	313
Y-12	N/A	988
Savannah River	234	(392)
Portsmouth	N/A	337
Los Alamos	50	116
Others	(4)	(49)
Total	2,736	1,316

Parentheses indicate net increase to the physical inventory.
Y-12 and Portsmouth do not process plutonium.

But cashiers can make mistakes that cause differences between the amount shown in the records and the amount actually on hand.

With cash registers, the differences may result from honest mistakes; for example, the cashier may enter the wrong amount on the keypad, or may enter the correct number but give too much, or too little, change for an item. In some cases, the differences will nearly offset each other) the cashier may make two mistakes, giving one customer too much change and another too little, with both errors involving about the same amount of money) so that the difference would be small, even though several larger errors were made. In other cases, the mistakes can be cumulative; the cashier may make two mistakes, both times giving too much change, resulting in a relatively large inventory difference.

A consistent pattern of such differences can indicate theft.

Differences would also result if the cashier deliberately diverts money from the cash register. A pattern of theft would result in a consistent trend of shortages in the cash register (or positive inventory differences). If there is a consistent trend of positive differences, the supermarket manager should suspect that either the cashier is dishonest (diverting cash) or is consistently making mistakes that favor the customer (equivalent to a measurement bias). In either case, the manager must investigate the reasons for the differences. If the system is working correctly, the manager should be able to detect dishonest cashiers by monitoring these differences. Also of concern, however, is the possibility that the dishonest cashier could divert cash and simultaneously manipulate the records (e.g., not ringing in sales that were actually made) to conceal the diversion.

Of course, inventory differences involving special nuclear material are more complex than those with cash registers. The book inventories must account for removals, decay corrections, transmutations, and production as well as both inter- and intra-site shipments and receipts. Inventory differences can result from remeasurements, inadequate measurements or estimates of material in holdup, poor or improper inventory techniques, changes in accounting practices, and general recordkeeping errors. However, the concept is basically the same, and inventory differences need to be investigated and explained.

Current inventory differences suggest that thousands of kilograms of material documented in Departmental records are not accounted for.

Two key points can be seen in DOE's inventory difference data: (1) the inventory differences are large, and (2) the inventory differences are overwhelmingly positive. The inventory differences involve thousands of kilograms of special nuclear material (2,700 kg of plutonium and over 1,300 kg of high enriched uranium). Positive inventory differences indicate a loss of special nuclear material, and negative inventory differences indicate a gain of special nuclear material.

The interpretation of cumulative facility inventory differences is complex and cannot be accomplished without recognizing that inventory differences are evaluated over a specified period of time at a localized level in a facility, called a material balance area, and not across the DOE complex. These evaluations, which may be followed by investigations and are always followed by resolution, are intended to ensure that apparent losses are not attributable to diversion or theft of special nuclear material. Reducing inventory differences is important to increase loss detection sensitivity in order to provide greater fissile inventory assurance.

Although most of these differences can be explained, they make it harder to detect theft or diversion of material.

Over the years, DOE facilities have spent much time and effort attempting to explain inventory differences. In many cases, the inventory differences have been attributed to holdup, operational losses, such as accidental spills, environmental releases, human errors, rounding errors, and disparities between old book values, which were often determined by inaccurate measurement equipment and techniques, and new measurement values, determined with today's more accurate equipment and techniques. The "unexplained" inventory differences are significantly smaller than the total inventory difference, but still involve over a thousand kilograms of uranium and over 500 kilograms of plutonium. Differences of this magnitude greatly hinder DOE's ability to detect missing material. In addition, these differences could create the appearance that the United States is not adequately accounting for special nuclear material, and could damage DOE's credibility internationally and with the American public.

Updated measurements could decrease the inventory differences, and increase confidence that material has not been diverted or lost.

The vast majority of the inventory differences occurred during the times when the DOE complex was producing and processing large quantities of special nuclear material, most notably prior to the mid-1970s when measurement capabilities were less precise and accurate, and accounting practices were less rigorous than today's standards. With improved measurements and accounting practices, the inventory differences that have resulted since the mid-1970s are significantly smaller. Appendix C provides a more detailed breakdown of the inventory differences by time period (pre-1988, when the DOE was producing and processing significant quantities of special nuclear material, and post-1988, when most production activities had effectively been halted). The current processing activities of the DOE complex are limited to dismantlement, repackaging, and recovery of special nuclear material in scrap materials. These activities can result in inventory differences. However, it is possible to use current measurement technology and rigorous materials accounting practices to minimize or thoroughly explain inventory differences.

Measuring values for holdup, which have only been estimated in the past, is likely to drive fluctuations in inventory differences in the near term.

Inventory differences will fluctuate positively and negatively as facility cleanup activities continue to identify and account for previously unmeasured holdup, and as remeasurement programs produce more accurate measurements. Although future activities will result in both positive and negative adjustments to the inventory difference, it is believed that the most important factor will be the identification and measurement of previously unaccounted-for holdup. As stated in the Secretary's press conference, "the current DOE special nuclear material inventories may not reflect all material that will be recovered during decontamination of buildings and equipment or material in waste."

The Department's credibility will improve with better material measurements and more defensible explanations for inventory differences.

The magnitude and longstanding nature of the inventory differences are such that they will never be fully localized and explained with a high degree of confidence. However, it is expected, although not assured, that better measurements and accounting, especially for holdup, will identify materials that have not been previously measured and accounted for, and thus will tend to reduce the magnitude of the inventory differences. In any case, better measurements and more defensible accountability values will help DOE to better understand the inventory differences and thus be better prepared to explain them to the public and the international community.

2.2 Accuracy of Inventory Values

Ideally, the inventory value, as stated in inventory records, accurately represents the actual amount of material on hand.

There are longstanding and well-recognized weaknesses in the accuracy of the special nuclear materials inventory values. The term "inventory value" refers to the amount of material (plutonium or uranium) reflected in the inventory records for an item. The goal of the accountability system is for the inventory value to accurately reflect the actual amount of material in the item. In practice, the inventory values can differ from the true amount of material for a variety of reasons. For example, a facility may estimate that there is one kilogram (1000 grams) of plutonium in an item, and record that amount as the value in the inventory record. However, it is possible that the estimate is based on incorrect assumptions and that the item contains only 800 grams. In such a case, the inventory value is inaccurate; the inventory value is 200 grams more than the true value.

Some methods for obtaining inventory values are very accurate; others are less so.

The accuracy of the inventory values depends on how they were obtained. Some methods for obtaining inventory values are very accurate, although even the most accurate measurement methods have some measurement error. For example, under optimal conditions, some methods can measure the amount of plutonium in an item to within a fraction of a gram. Other methods are considerably less accurate; the inventory value for the material in scrap material or floor sweepings may be little more than a rough estimate based on operational experience.

Many facilities have not been able to meet the requirement that inventory values be based either on actual measurements or on documented, technically defensible estimates.

DOE orders require all inventory values to be based on actual measurements if measurements are feasible. If measurements are not feasible, the inventory values must be based on documented and technically defensible methods. Many facilities do not meet these requirements. The current DOE inventory values were obtained by numerous methods, including measurements by both destructive and nondestructive analysis, engineering estimates, and by-difference calculations (a calculational technique that assumes all material that is not in the measured quantity is in a residual item or a waste or scrap stream). Many of the inaccurate inventory values stem from the early years of the weapons program, when the inventory values were based on estimates or inaccurate measurement techniques and equipment. Additionally, Security Evaluations inspections have identified specific deficiencies in measurements, including measurement systems that were not calibrated or initially qualified, inadequate measurement control programs, material that was not independently measured by the shipper and receiver, and unmeasured material.

Concerns about inventory values are generally limited to byproduct materials, such as impure oxides, scrap, and holdup.

The inaccurate values are limited to certain types of materials. Most of the special nuclear material in the DOE complex is in the form of weapons components, pure oxides (including mixed oxides of plutonium and enriched uranium), reactor fuel, and pure products (such as metal plutonium buttons, or uranium hexafluoride). With a few isolated exceptions (such as materials in solutions), the inventory values for completed items and pure products are reasonably accurate and meet established accountability requirements. However, there are significant concerns with inventory values for certain byproducts of the weapons production process, such as impure oxides (including mixed oxides of plutonium and enriched uranium), scrap, residue, and holdup (residual material in equipment that is not easily removed). Many of the recorded values for these materials are based on inaccurate measurements, are estimated, or cannot be defended because of lack of appropriate records.

Scrap and impure oxides comprise about 10,000 kg of plutonium and 100,000 kg of high enriched uranium. The amount of holdup cannot even be estimated.

Although these concerns are limited to certain types of materials, the magnitude of the problem is significant. While scrap and impure oxides represent only about 10 percent of the special nuclear material inventory, the amount of such material is immense **)** approximately 10,000 kg of plutonium and nearly 100,000 kg of high enriched uranium. Much of the scrap material lacks adequate inventory values. Inventory values for holdup are perhaps an even larger concern. Some holdup has never been measured, and the accuracy of early holdup measurements is not much better than an estimate. Other holdup has been estimated in a variety of ways, including calculating holdup as the difference between the amount of material that entered a processing stream and the amount that came out (one form of by-difference accounting). Some DOE facilities have not accounted for their holdup at all.

Currently, the differences between recorded inventory values and actual values are unacceptable by international standards.

The accuracy of inventory values is a widespread concern, affecting most DOE facilities that were involved in special nuclear materials production or weapons production. Inaccurate inventory values are evident even at facilities that traditionally had access to state-of-the-art measurement equipment, such as national laboratories (where much equipment and many methods were developed). The concerns about inventory values are demonstrated by the inventory verification programs at Los Alamos National Laboratory and Lawrence Livermore National Laboratory, which resulted in a combined measurement difference of approximately six kilograms of plutonium. Such a large difference is close to the amount (eight kilograms) considered a "significant quantity" by the International Atomic Energy Agency (IAEA). IAEA inspections are designed to detect the diversion of a significant quantity; failure to account for such an amount could trigger international concerns about proliferation. It is likely that even larger measurement differences will result when inventory values are re-evaluated and remeasured at facilities that processed larger amounts of special nuclear material (e.g., some of the facilities at the Hanford Site, Idaho National Engineering Laboratory, Savannah River Site, the Y-12 Plant, Rocky Flats, and enrichment plants). Large measurement differences make it difficult to verify that no theft or diversion has occurred. Further, differences of several kilograms will be difficult for the public and the international community to accept.

To address these concerns, all special nuclear materials having inadequate inventory values should be measured and placed into accountability records.

It is necessary to have accurate values for all of the DOE special nuclear material inventory to prevent concerns related to health, safety, criticality, and theft/diversion for material disposition and long-term storage. Further, DOE needs to have accurate inventory values so that DOE's will tally with the independent measurements performed during international and bilateral inspections. During the transition of facilities to Environmental Management, inventory values are necessary to assist in planning, assure adequate program funding, and maintain appropriate protection levels. To assure accurate inventory values, all special nuclear material, including holdup, should be measured and placed into the accountability records. Inventory values that are suspect for any reason) inadequate measurement technologies, nonexistent audit trails, inaccurate estimates, or by-difference calculations) should be updated by measuring the material in its current configuration, if amenable to measurement.

Options for obtaining adequate inventory values for unmeasured materials are discussed in Section 4.1. The unique concerns associated with holdup are discussed in Section 4.2.

2.3 Measurement Technology and Processing Activities

Nondestructive analysis is the only viable measurement technology for scrap, impure oxides, and holdup.

Two general types of measurement methods are used for special nuclear materials: destructive analysis, and nondestructive assay (NDA). In destructive analysis, a representative sample is selected from a batch of material and analyzed. The results are extrapolated to the entire batch. Destructive analysis is used for homogeneous materials found in special nuclear material product streams and processing plants, where samples can be obtained from process lines and tanks. Using destructive analysis for materials such as scrap, impure oxides, holdup, and process residues is often impractical and can lead to erroneous results due to inhomogeneity of the material and the resulting sampling error. Thus, the material of greatest interest to this study) scrap materials and holdup) are not amenable to measurement using destructive analysis techniques.

It accurately indicates the type and quantity of special nuclear material in an item by measuring the material's characteristic radiation.

In NDA, the type and amount of radiation or heat emitted by the material are characterized and measured without altering the material in any way. NDA measurements can be performed without removing the material from its shipping/storage container. Because each type of special nuclear material emits a characteristic type of radiation, and because the intensity of the radiation emitted is proportional to the quantity of material present, many times NDA techniques can accurately indicate the type and quantity of material present. Appendix D provides technical details on measurement equipment. Additional information about measurement uncertainty and measurement differences is included in Appendix E.

The advantages of nondestructive assay have led to its wide use.

NDA is the primary measurement method used for scrap, impure oxides, and holdup. NDA is also the only technique that can measure holdup in such areas as process piping, ductwork, and equipment. Other advantages of NDA include the ability to measure an entire item, not just a sample; fewer processing steps; and reduced personnel exposure as a result of quicker measurement times, greater distances, and better shielding. These advantages have led to the wide acceptance of NDA, and all sites use it to some extent for accountability measurements.

Technological advances make it feasible to measure most types of materials at DOE facilities.

After more than three decades of development, NDA equipment and techniques have reached maturity. The principles, the pitfalls, and the applications of the techniques are well understood. Although the material in DOE facilities varies in composition and physical and chemical form, it is technically feasible to use modern NDA equipment and techniques to accurately measure much of the material at DOE facilities, including materials that could not be adequately measured when they were generated. However, modern techniques have not been widely applied to address the recognized problems with scrap, impure oxides, and holdup for two basic reasons: (1) individual sites do not have the necessary equipment or techniques or appropriate calibration standards, and (2) measurement operations are limited by resource availability, facility shutdowns, or safety and health concerns.

The most up-to-date equipment is not readily available to many facilities, and lack of Department-wide standards has limited this equipment's usefulness.

At many DOE facilities, the measurement equipment is outdated, and more up-to-date equipment is not readily available on the site. NDA measurement methods are complex and must often be refined for specific material forms; it is often necessary to develop site-specific representative and traceable standards and techniques, which can be time consuming and resource intensive. Some of the limitations on measurement capability result from an imbalance in the availability of NDA equipment across the complex; some facilities lack equipment, and others have equipment that is underutilized. Further, the lack of standardized measurement programs hinders the sharing of resources. The enhancements identified in Section 4.3 can partially address these concerns.

Operational problems have also limited the application of modern methods.

Even at facilities that now have suitable equipment, much material has been in storage for extended periods and has not been measured since suitable equipment was obtained. In some cases, cessation of processing activities has precluded facilities from processing scrap materials into a form that can be measured. At other facilities, health and safety issues (such as high dose rates) have limited measurement operations, or have severely limited access to areas where the materials are located. In some cases, the equipment is available and there are no technical reasons that measurements cannot be performed, but not enough attention or resources have been directed toward dealing with unmeasured material.

Processing activities are limited at DOE, but decisions about plutonium processing and measurements must be made soon.

High enriched uranium processing activities for the past five years have been centered on the Y-12 and Savannah River facilities. These activities were intended to consolidate the material into a more stable form for long-term storage. So far, there has been minimal scrap/waste processing; because of the large amount of scrap materials, efforts should be accelerated to reduce the volume of scrap materials by converting the material into a more measurable form. There has been no plutonium processing activity during the past five years. When processing was terminated, some materials were left in a relatively unstable condition. Several unsuccessful attempts have been made to initiate recovery processes, but plans were changed; additional safety analyses or operational requirements were imposed; seismic modifications were required; concerns about environment, safety, and health hazards were not resolved; stakeholder and Defense Nuclear Facilities Safety Board concerns were not fully addressed; or additional requirements were placed on DOE contractor facilities. Because some forms of plutonium are unstable, only quick action can assure that environment, safety, and health hazards do not occur while processing activities are being planned. Mixtures of plutonium and high enriched uranium present special problems. Most of this material is currently stored at the Rocky Flats Plant, and there are no existing processing or recovery operations for this material. Any activity to address the problems created by the disposition of this material should include fissile inventory assurance for both the plutonium and the high enriched uranium.

3.0 INCENTIVES FOR IMPROVEMENT

Accurate accounting is needed for protection of special nuclear material, international and bilateral inspections, and safety and health assurance.

The primary reason for maintaining an accurate material accounting program is to provide documented assurance that material control and physical protection have met their purposes to protect special nuclear material against theft and diversion. In addition to protecting special nuclear material, other factors stimulating enhancement of the measurements program include planned bilateral and IAEA inspections, and the need for accurate information about special nuclear materials to provide for worker safety, criticality safety, and reduced radiation exposure, particularly during environmental restoration activities. This section discusses the impacts of the recognized accounting weaknesses and the incentives to improve the program both for the primary program objective **)** protection of special nuclear material **)** and for the secondary, but increasingly important, objectives associated with international inspections, decontamination and decommissioning, and safety and health.

3.1 Protection of Special Nuclear Material

Material accounting provides assurance that material has not been lost, diverted, or stolen.

Material accounting, as used here, includes accountability systems, physical inventories, and measurement programs. Material accounting is one part of an integrated safeguards program, which also includes special nuclear material controls (including elements such as material containment, material surveillance, and tamper-indicating devices), physical security (including elements such as access controls, intrusion alarm systems, and protective force patrol and response), and personnel security. The primary purpose of the integrated safeguards system is to protect special nuclear material. The material accounting program contributes to this goal in two ways: (1) it provides a means of detecting the loss of special nuclear material, and (2) it provides assurance that material has not been diverted or stolen **)** that is, the other elements of the integrated safeguards system have been effective.

The Department has allowed facilities to compensate for weak accounting systems by strengthening physical protection.

DOE has always considered "defense-in-depth" as a fundamental principle of the integrated safeguards system. The defense-in-depth concept requires multiple layers of protection. For example, special nuclear material may be stored in a vault, which is contained within a material access area, which is in turn contained within a protected area. Access controls, intrusion alarms, material containment, and other appropriate safeguards features are included in each layer. If properly implemented, the defense-in-depth strategy assures that failure of a single protection element will not result in the loss of special nuclear material because multiple layers must be defeated. Consistent with the defense-in-depth concept, DOE has permitted facilities to use additional physical protection measures to compensate for acknowledged material accounting weaknesses if accountability measurements were impractical. The defense-in-depth and graded safeguards strategies provide for operational flexibility and cost savings, and may have been consistent with national priorities during the Cold War and arms buildup. However, these approaches have created a physical inventory of items whose values are subject to question and, as discussed in Section 3.2, may create concerns from an international perspective since some inventory values are not defensible by international standards.

Thus, despite weaknesses in accounting, there is little risk of major theft or diversion of special nuclear material.

As discussed in Section 2, there are significant weaknesses in material accounting, most notably with scrap and holdup. The lack of accurate and reliable inventory values for certain types of special nuclear materials in DOE's inventory forces a greater reliance on other elements of the integrated safeguards program to ensure adequate protection. However, the risk of theft or diversion of strategic quantities of special nuclear material is low at most DOE facilities for a number of reasons:

- DOE's defense-in-depth strategy provides assurance that an adversary would have to circumvent multiple layers of a system to remove strategic quantities of special nuclear material from a facility.

- Other elements of the integrated safeguards program, such as physical security measures and material controls, are in place and generally effective. Although some weaknesses have been noted in protective force and physical security system performance) such as failures of individual sensor layers, and a general overreliance on labor intensive measures) inspections generally indicate that physical security programs are meeting their mission objectives.

- There are relatively few opportunities for theft and diversion since weapon production operations have ceased and nearly all of DOE's special nuclear materials inventory is in static storage.

- Recent events, such as those in Germany involving Russian plutonium, indicate that groups interested in obtaining special nuclear material can find easier ways to get it than stealing it from DOE facilities.

Removal of existing security measures could create vulnerabilities.

Further, there is no evidence that strategic quantities of special nuclear material have actually been diverted from DOE facilities; if such diversions had occurred, one would expect incidents of nuclear terrorism, or threats or claims to possess United States special nuclear materials. However, recent trends, such as removal of security measures at facilities that are being decommissioned or that have reduced special nuclear material inventories, may negate the basis for accepting less than adequate material accounting practices.

However, an accurate inventory will provide assurance that material has not been diverted.

Although the current risk of theft or diversion of special nuclear material may be low at most facilities, an accurate inventory of special nuclear materials is necessary to provide assurance that material has not been stolen or diverted. Without such assurance, facilities may have difficulty with threats such as extortion because it would be difficult to determine whether a claim to have diverted material was credible. For some types of material, such as scrap and holdup, reliable information is not available. As a result, DOE has only a limited ability to know whether any of this material has been stolen or diverted and, if so, how much. Such issues become more significant as DOE places special nuclear material in long-term storage. Holdup represents a unique concern and is discussed further in Section 4.2.

Protection of special nuclear material is only one issue driving the need for better inventory assurance.

The current effectiveness of the integrated safeguards program must be one of the most important factors when considering whether to perform additional measurements. Based on safeguards considerations alone, additional measurements are not always cost effective, either because the current risk is considered acceptable or because resources may be better devoted to other aspects of the safeguards program. However, the effectiveness of the current safeguards should not be the only consideration. Other factors, such as the upcoming international inspections, holdup concerns, planned reductions in physical security measures, and preparation for long-term storage, need to be considered as well. Taken together, this combination of factors often indicates a need to increase the level of assurance in the fissile material inventory.

3.2 International and Bilateral Inspections

To promote nonproliferation, the Department will open facilities to international and bilateral inspections.

As one part of an effort to emphasize and promote nonproliferation, DOE plans to open some of its facilities to international and bilateral inspections. DOE is offering U.S. fissile material that is excess to the national deterrent to IAEA inspections. This offer is being made within the framework of the existing U.S.-IAEA Safeguards Agreement, which requires technical verification of fissile inventories, including measurements. The IAEA has already conducted site visits at several facilities, and bilateral agreements with Russia are under consideration. Thus, DOE facilities must be prepared to demonstrate fissile inventory assurance and to comply with international and bilateral agreements.

International inspections involve different techniques, and different goals, than the Department uses.

The terms of international and bilateral agreements may create a set of requirements for DOE facilities that are very different from those in DOE orders, reflecting the different purpose of IAEA inspections. DOE accountability values are intended to provide assurance that special nuclear material is accountable and to detect theft or diversion by a single individual (e.g., the insider threat), or a small number of individuals in collusion. Thus, DOE is concerned with both accountability and compensatory measures that protect special nuclear material. The IAEA inspections are conducted with a different purpose: to independently verify the facility's values. IAEA is concerned with the potential for facility-wide collusion in addition to the more limited threat posed by individuals. From the IAEA perspective, compensatory measures are not a factor. Consequently, international inspection teams will often use different measurement equipment, methods, and data analysis techniques to analyze special nuclear material inventory values. The differences in approach will inevitably result in differences between the DOE inventory values and the measured values obtained by international inspectors. DOE must adequately explain, analyze, and investigate these differences to assure that DOE does not violate international treaties.

The Department's inventory values do not currently meet international standards.

Currently, DOE does not have sufficiently accurate information about some types of materials present (most notably holdup and scrap) to meet IAEA standards. For example, the presence of inadequately measured holdup would not be defensible from the perspective of international inspection. Holdup that is not reflected in the inventory at all, as is the case at some facilities, could be a particular problem. Also, DOE's defense-in-depth approach has allowed facilities to use other safeguards measures to compensate for questionable inventory values for some materials, such as scrap. Although this strategy may have been acceptable for DOE's purposes, it creates concerns from an international perspective because international inspections focus on inventory values and do not normally recognize compensatory safeguards measures.

Certain Departmental policies may actually conflict with international standards.

Policy differences between DOE and the international nuclear community may affect the implementation of international and bilateral treaties and the perception of compliance with those treaties. Material accounting policy changes may be appropriate for national purposes, but may be inconsistent with international standards. For example, DOE allows longer periods between inventories (that is, extended inventory frequencies) for material in long-term storage if adequate safeguards can be demonstrated, perhaps through continuous surveillance or enhanced physical security. While extended inventory frequencies may reduce personnel radiation exposures, they can conflict with the frequencies required by the IAEA.

The Department should begin a coordinated effort to bring inventory values and policies in line with international requirements.

DOE can minimize the potential for negative consequences by increasing the level of assurance in its special nuclear materials measurement program. In addition, DOE should develop a consolidated approach to IAEA and bilateral inspections that is consistent across DOE facilities. Agreements need to address consistency of measurement equipment, determination of physical inventory sample sizes consistent with "as low as reasonably achievable" (ALARA) concepts, pre-existing inventory differences, and inventory frequencies. The differences in policy and approach should be resolved with the IAEA before the inspections begin to avoid the appearance that the United States is not adequately protecting its special nuclear materials.

3.3 Safety, Health, and Decontamination Issues

DOE is attempting to address safety and health concerns.

In addition to safeguards and international inspections, inadequate estimates of special nuclear material holdup affect worker safety and health. DOE has initiated a number of actions to promote safe and secure storage and dispositioning of special nuclear materials and decontaminating and decommissioning of DOE facilities. The Secretary of Energy established the Nuclear Materials Disposition Team in January 1994 to develop Departmental recommendations and direct implementation of decisions concerning disposition of excess special nuclear materials. The objective of that team is to provide for safe, secure, and environmentally sound control, storage, and ultimate disposition of surplus fissile materials. Characterization of special nuclear material, including the determination of inventory quantities, is extremely important to this effort, and is an integral component of disposition activities. In addition, the Plutonium Vulnerability Assessment Team was established to identify environment, safety, and health vulnerabilities; existing compensatory measures; and near- and long-term upgrades to correct identified deficiencies.

Unstable materials are an immediate concern. However, there are obstacles to resuming processing.

The unstable forms of special nuclear material present a major concern for the DOE complex. The cessation of processing has resulted in some materials being stored in containers for much longer periods than were usual during weapons production. Such situations have already resulted in significant hazards, such as overpressurization of plutonium oxide containers. Also, some forms of special nuclear material can be pyrophoric. The Plutonium Vulnerability Assessment Team will identify material that must be processed to a stable form suitable for long-term storage. Once the material and process have been determined, the priority activities must be accomplished in a timely manner. To accomplish the needed processing, funding must be identified and other constraints, such as environmental protection or safety issues, must be resolved. In some cases, processing activities may be in conflict with other directives or requirements. For example, Executive Order 12856 requires federal facilities to report all releases of specified chemicals, and advocates a 50 percent reduction in releases. Currently, DOE is performing little processing and thus is releasing only small amounts of the chemicals used in processes (e.g., nitric acid). However, it is becoming increasingly important that processing be restarted to address concerns such as unstable materials. Restarting processes, however, will result in increased releases, and make it difficult or impossible to meet the 50 percent reduction target. Such difficulties must be addressed on a DOE-wide basis, recognizing the potential conflicts between health and safety issues and environmental protection goals.

Accurate knowledge of the amounts and locations of material and reduction in inventory frequencies help control worker exposure.

From a worker safety and health standpoint, the primary concerns associated with special nuclear material are exposure to radioactive or toxic materials, and criticality safety. Plutonium (and to a lesser extent uranium) in storage or holdup can result in significant personnel exposure. Controlling exposure to radioactive materials such as plutonium requires an accurate knowledge of their locations and quantities. Unmonitored accumulations of material can result in unnecessary and unexpected exposures.

Additional measurements may entail additional radiation exposure.

Another factor that must be considered is the exposure received by personnel performing inventories and measurements. In an effort to reduce personnel exposure, the Office of Safeguards and Security has issued guidance allowing extended inventory frequencies through the use of alternative safeguards and security measures and reduced access to the storage location. Although few DOE facilities are currently implementing this guidance, many are assessing the potential of existing technologies and facility-specific features to extend inventory periods. In making decisions about additional measurements, radiation exposure must be considered.

Criticality safety also depends on knowledge of material amounts and locations.

Criticality safety involves spacing requirements and mass limits that require knowledge of the amount of material in each item, or assurance that the amount of material is not underestimated. For some types of materials, DOE does not have sufficient confidence in the inventory values to assure that criticality limits are strictly observed, and over-conservative analyses may result in reduced storage efficiency. Accumulations of holdup can also cause criticality concerns. Special nuclear material has accumulated in places where it was not accounted for, in some cases resulting in an accumulation that exceeds criticality safety limits. Such unplanned and unmonitored accumulations have contributed to some of the criticality incidents that have occurred at DOE facilities.

Decontamination activities lead to special concerns in safety and health.

In many ways, there are increased hazards associated with the cessation of production and the shift of DOE facilities to a decontamination and decommissioning mode. For example, physical inventories pose a greater health and safety risk to personnel performing safeguards activities because of the increased amounts of special nuclear material in storage as a result of weapons returns and special nuclear material consolidation efforts. Also, disassembly and decontamination efforts require many non-routine activities (e.g., cutting into piping and equipment) involving hazards that are difficult to predict and control. Accurate information about special nuclear materials is needed to assure personnel safety, criticality safety, and minimal radiation exposure during decontamination and decommissioning activities. An estimate of the amount of special nuclear material holdup in process equipment is particularly important during decontamination and decommissioning. Process systems that require dismantling present additional hazards because material can become airborne when the systems are cut into or unbolted. Also, moving or transporting equipment can jostle accumulations of material, possibly leading to a critical mass.

Accurate inventory information is also needed for decontamination and decommissioning planning.

In some cases, DOE does not have sufficiently accurate information on hand about its special nuclear material inventories to allow DOE facilities to properly plan for decontamination and decommissioning activities. Equipment removal and decommissioning activities require an accurate knowledge of the location of all special nuclear materials, including holdup. Because of the potential impacts on worker safety, precautionary measures must be taken to deal with the worst-case scenarios in the absence of reliable information about the amount of holdup. These measures can hamper cleanup activities and increase the cost. Material that has not been identified or quantified could cause contract renegotiation to address the cost of additional safety equipment and resources to adequately complete the job.

Cleanup and disposition efforts rely on accurate inventory values.

DOE's efforts to dispose of excess special nuclear material and clean up its weapons production facilities could be hindered by the lack of accurate information about the amount and types of material present in those facilities. These consequences can be minimized by increasing the level of assurance provided by DOE's special nuclear materials accounting program, as discussed in Sections 4 and 5. With knowledge of the location and amounts of holdup and effective programs to monitor that material, facilities can enhance worker safety by instituting appropriate access controls and radiation and criticality safety measures. Also, knowing the locations and quantities of holdup should allow better estimates of the costs and timelines for decommissioning activities.

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4.0 PROBLEM AREAS AND POTENTIAL ENHANCEMENTS

Problems include unmeasured materials, holdup, equipment usage, remeasurements policy, terminology, and shipper/receiver documentation.

This section provides a more detailed discussion of areas identified as significant problems affecting inventory assurance. These include approaches for obtaining adequate values for unmeasured materials, the unique concerns associated with holdup, lack of standardization and underutilization of equipment, lack of a policy covering remeasurements, inconsistencies in terminology, and numerous unclosed shipper/receiver transactions. For each identified problem area, potential program enhancements are identified.

4.1 Unmeasured Materials

Scrap and holdup are the primary forms of unmeasured material.

As discussed in Section 2, most unmeasured materials are categorized as scrap or holdup, although there are other types of materials that do not have defensible values (e.g., solutions in tanks that have not been properly calibrated). Scrap is traditionally defined as material that is not product and from which it is economically feasible to recover usable special nuclear material. For the purposes of this study, impure oxides are included in the list of traditional scrap materials. Using this definition, DOE possesses approximately 10,000 kg of plutonium scrap and nearly 100,000 kg of high enriched uranium scrap **)** representing approximately 10 percent of the DOE material inventory **)** and the amount of scrap is increasing. The unique concerns associated with holdup are discussed in Section 4.2.

Obtaining defensible values for these materials will provide significant benefits, although costs and impacts must be considered.

The accountability values for most scrap and some other materials are not defensible. Much of the material has not been measured, and even when measurements exist, their accuracy is suspect or not well documented. To address concerns associated with inadequate inventory values, DOE should assure that all such materials are adequately measured and entered in the accountability books. Better inventory values will enhance fissile inventory assurance and reduce the risk of theft or diversion of special nuclear material. Accurate inventory values will also better prepare DOE for international inspections, enhance worker safety, and enable both Headquarters and facilities to better determine their budget needs and develop strategic plans.

Although there are significant benefits to measuring materials, there are also costs and impacts that need to be considered. Scrap material is found in a wide variety of forms, and the environment, safety, and health risks are substantial for some of these forms. Even characterizing the constituents of scrap material accurately is difficult. An aggressive program to measure all materials would provide the most timely solution to the unmeasured material issue. However, such an approach may be prohibitive from a radiation exposure perspective, particularly when dealing with plutonium.

Prioritizing the materials to be measured may be desirable from a health and safety standpoint.

An alternative approach to measuring all of the material in one campaign is to stratify the physical inventory into items with adequate measurements and those without adequate measurements. At the time of the physical inventory, facilities would select a statistical sample of both populations, more heavily weighted toward the unmeasured items and with consideration of material category and attractiveness level. The items selected would be measured using methods and instrumentation that provide quantitative values. As the population of unmeasured items decreases, the statistical sample should be modified to address the remaining unmeasured material. Although this stratified sampling approach would delay measurement of some items, this approach may be preferable from the standpoint of worker health and safety. Decisions about conducting measurements should be made systematically, considering all the benefits and impacts.

4.2 Holdup

The various problems with holdup are widespread.

All special nuclear material processing equipment contains residual material that was in the equipment when operations were suspended. This material, commonly referred to as "holdup," is not easily removed, and has been an ongoing problem within the DOE complex. The presence of holdup that is not adequately reflected in the inventory values can result in opportunities to defeat safeguards and remove special nuclear material without detection. As discussed in Sections 3.2 and 3.3, inadequate estimates of holdup affect not only safeguards but also worker safety, cleanup activities, planning and contracting, and international inspections.

The practices for accounting for holdup are inconsistent across DOE.

At many facilities, holdup is not accurately reflected in the special nuclear material inventory due to inconsistent accounting practices, lack of measurements, or large measurement uncertainties. Facilities' approaches to account for holdup have been inconsistent; at some facilities holdup is quantified, accounted for, and monitored on an ongoing basis, while at other facilities it has been either estimated, or not addressed and thus assumed to be zero. Most of the holdup at DOE facilities has not been accurately measured, and some has not been measured at all. When measurements are made (see Figure 4), they typically have uncertainties of 25 to 50 percent because of assumptions concerning the distribution of the material, the physical and chemical forms of the material, the depth of the material deposit, and the process containment materials. See Appendix E for a more detailed discussion of holdup measurement uncertainties.

The presence of holdup represents a unique safeguards concern. At many facilities, holdup inventory values are not sufficiently accurate to reliably detect a

Figure 4. Holdup Measurements

Protection of material in holdup is of particular concern at facilities that are downgrading their physical protection measures.

diversion of a significant quantity of special nuclear material, and at some facilities, holdup is not reflected in the inventory at all. In such cases, there is no mechanism for the accountability systems to detect theft or diversion of material in holdup, and the safeguards program must rely exclusively on physical security measures, such as access controls and search systems, and material controls, such as surveillance procedures and daily administrative checks. The potential for diversion is particularly significant at facilities that are reducing physical security measures to facilitate decontamination and decommissioning efforts. Better estimates of holdup values can enhance confidence in special nuclear material safeguards by providing a mechanism for detecting diversion and assuring that the material is monitored and accountable.

The Department offers training in holdup issues.

Within the DOE safeguards community, there is a growing awareness of the significance of issues associated with holdup. Some facilities are taking proactive measures to locate, quantify, and account for holdup in order to address safeguards, facility transition, decontamination and decommissioning, health and safety, and criticality concerns. In an effort to address holdup concerns, DOE Headquarters sponsored the development of a training course for the measurement of holdup, which is presented by subject-matter experts at Los Alamos National Laboratory.

A systematic approach to holdup would provide a number of benefits.

Although some measures have been taken and some facilities have been proactive, not all facilities are taking the measures that will be necessary to fully address holdup issues. Holdup requires attention and scrutiny in all aspects, including physical security and material control, as well as increased measurement accuracy. The following enhancements are needed to address concerns associated with special nuclear material holdup in equipment:

- All material in holdup should be adequately measured and entered in the accountability books. Where measurements are not practical in the near term, holdup should be estimated and entered in the books.

- Each facility should review holdup from the overall safeguards perspective, including consideration of the adequacy of physical security measures and material controls in detecting and preventing unauthorized access to or removal of special nuclear material. Facilities that are reducing physical security measures to reduce costs or facilitate access should pay particular attention to the potential for diversion of special nuclear material holdup in process equipment.

- Decontamination and decommissioning activities should include holdup validation to provide measurement personnel with data that can be used to improve holdup measurements in the future. Now that DOE is decontaminating and decommissioning many of its production facilities, DOE has a unique opportunity to remeasure much of the holdup during process cleanout activities. Such measurements could validate previous holdup measurements and reduce the uncertainty.

These enhancements provide a number of benefits to DOE:

- Analysis of holdup from the total safeguards perspective, together with better accounting and monitoring of holdup, will enhance safeguards programs and reduce the risk of theft or diversion of special nuclear material.

- Determining measured values for holdup and implementing proper accountability will increase fissile inventory assurance and better prepare DOE for international inspections.

- Accurate knowledge of the quantities and location of holdup will enhance worker safety by allowing facilities to implement appropriate safety measures during decontamination and decommissioning.

- Knowledge of holdup quantities will enable both Headquarters and facilities to better determine their budget needs and develop strategic plans.

However, measuring holdup involves significant costs and impacts.

Although there are significant benefits to measuring holdup, there are also costs and impacts that need to be considered. Measuring holdup is often labor-intensive, physically demanding, and potentially hazardous, both from radiation and from environmental conditions (although hazards can be controlled with proper safety measures and the use of shielding to minimize radiation exposure). Further, there are limitations on the accuracy that can be achieved due to measurement uncertainties (see Appendix E). A systematic approach to decision making about conducting these measurements should consider all the benefits and impacts.

4.3 Measurement Systems Usage and Standardization

Material accounting programs would benefit from better resource utilization and standardized equipment.

Although measurement techniques exist for scrap materials, some measurement equipment is not being fully utilized within the DOE complex. In some cases, the appropriate equipment has been purchased but remains idle because facilities have been shut down, missions have changed, or environment, safety, and health concerns have restricted the measurement system's use. Such problems need to be addressed through a prioritized action plan such as that described in Section 5. In other cases, material is not being measured because sites do not have the appropriate types of NDA equipment and trained personnel to measure their special nuclear material or because standards have not been developed. This section discusses the potential to enhance the DOE material accounting program by better using the available resources, both equipment and trained personnel, and by standardizing measurement systems where feasible.

Many sites do not have access to the equipment and trained personnel they need.

A review of measurement equipment across the complex indicates an imbalance in the availability of NDA equipment and trained personnel. Some sites do not have needed equipment, or are in the process of procuring it, while other sites have equipment that is underutilized or is no longer needed. For example, three DOE sites (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and the Y-12 Plant) need a californium shuffler to accurately measure their special nuclear materials, and two of those sites are in the process of procuring these costly instruments. However, a Nuclear Regulatory Commission site (Nuclear Fuel Services - Erwin Plant) has two californium shufflers that are not being used and for which no future use is projected. Although existing sample-well sizes and interrogation-source configurations for the available instrumentation are somewhat facility-specific, components could be used in addressing measurement needs within the DOE complex. It may be possible to make this equipment available to the sites that need it, avoiding some of the cost of procuring such components. Similar cases with other types of measurement equipment exist across DOE.

Material can be sent out for measurement, or equipment and personnel can be brought in.

There are two possible approaches for making better use of underutilized equipment: (1) equipment and trained personnel could be sent to the facilities where measurements are needed, or (2) special nuclear material to be measured could be shipped to the facility that has the equipment and trained personnel. Both approaches may be needed to address specific situations because some equipment is difficult to move, and some materials are difficult or hazardous to ship. Although there are potential benefits to making better use of existing equipment, obtaining the equipment itself is only a fraction of the cost of the total measurement system. Other factors must be considered as well: proper environmental conditions for equipment operation must be established; criticality, health, and safety reviews must be conducted; appropriate standards must be developed to calibrate the instruments; procedures must be developed; and the equipment must be approved for use. These factors are discussed in more detail in Appendix D.

Standardizing the analytical software and the containers for material to be measured would facilitate measurements.

The transfer of measurement equipment and personnel among DOE facilities would be facilitated by increased standardization of measurement systems across the complex. Each site must devote considerable resources to efforts such as requalifying methods, reviewing and updating procedures, and retraining measurement personnel. Currently, DOE facilities' measurement programs vary in many ways, including measurement training and techniques, standards for NDA measurements, and storage containers. Given the limited number of NDA measurement techniques, there are opportunities to standardize some of these elements throughout the DOE complex. Appendix D provides additional detail on measurement software and containers.

Standardized training, procedures, and calibration methods would also help.

The DOE Central Training Academy and national laboratories provide basic instruction in the theory and techniques of measurement systems. However, there are differences in implementation at the DOE sites. In addition, there are variations in the approaches used to develop and requalify methods. Although some variation is expected and necessary, these differences should be minimized to reduce the likelihood of measurement systems generating inaccurate results. Further, standardizing training programs, procedures, and standards for the optimum measurement techniques for plutonium and uranium can reduce operating costs associated with program maintenance.

Development of a standard container for measuring materials should also consider requirements for long-term storage.

All special nuclear material must be put into containers for movement and storage. With the exception of the 55-gallon drum, the type and size of these containers vary from site to site. Standardization of the 55-gallon drum has facilitated development of standardized and efficient measurement methods that are in common use across DOE and other facilities. Variations in other containers, such as waste boxes, cans for oxide, and cans for metal, have limited the ability to standardize NDA instrumentation and have necessitated the design and fabrication of unique systems. In general, these site-specific NDA systems differ only in their design to accommodate a specific container size, even though the special nuclear material contents are similar. If containers were standardized for uranium and plutonium oxide, weapons components, and scrap, other NDA systems could be standardized. Such standardization could improve measurement performance and reduce the magnitude of differences between similar measurements on different NDA systems. Standardization of containers for measurements should be coordinated with the standardization of containers for long-term storage.

Software variations cause artificial inventory differences and can be largely addressed through good configuration control.

NDA software is another area where better configuration control would enhance the material accounting program. Variations in NDA software have contributed to inventory differences and shipper/receiver differences. When an item is measured on two separate NDA systems with different software, an artificial difference in the measured value can occur. During consolidation and decontamination/decommissioning activities, more such artificial anomalies can be expected. Software variations, if not monitored by a measurement control program, can create further anomalies that may necessitate unwarranted investigations. In addition, when codes are updated, facilities do not always remeasure containers or recalculate previously measured values. Further, software improvements and modification are often not available to facilities until they are implemented by commercial vendors. Better configuration control would help to standardize the software, minimize measurement differences resulting from software variations, and provide traceability to a national software code. Source code listings and compiled codes should be made available to commercial vendors and all DOE facilities after they are documented and evaluated, thus helping facilities to assure that vendor-supplied equipment uses the most recent software improvements.

The following actions are needed to enhance the DOE material accounting program in measurement systems usage and standardization:

- DOE Headquarters should lead a complex-wide review of the availability of measurement equipment and facility needs. DOE Headquarters could coordinate the measurement needs of individual facilities with underutilized resources (including both unused equipment and trained and qualified personnel) available at other facilities.

- Efforts to standardize NDA measurement systems and techniques across the DOE complex should be increased. DOE Headquarters should conduct benchmarking studies for the most common material types to identify optimal methods for conducting measurements, providing training, and qualifying and certifying standards. These methods should be disseminated, and their use should be encouraged where they are feasible and cost effective.

- NDA software should be controlled by a single point within the DOE, and the most current source code listings and compiled codes should be available to all DOE facilities. Where feasible, NDA software should be standardized for specified types and forms of material.

- Containers for uranium and plutonium oxide, weapons components, and scrap should be standardized to meet requirements for both measurements and long-term storage.

These enhancements provide a number of benefits to DOE:

- Better use of available equipment and personnel resources

- More accurate, reliable, consistent, and defensible measurements

- Reduced operating costs associated with program maintenance

- Reduced differences between similar measurements made on different NDA systems, and a corresponding decrease in unnecessary investigations

- Reduced measurement differences resulting from software variations.

Standardization will, of course, require coordination and consensus to determine the optimal techniques. The approaches described in Section 5 will help to achieve the desired results and potential benefits.

4.4 Remeasurements Policy

Current policy does not address the remeasurement of items prior to packaging or limited reprocessing. Because these activities are an integral part of ongoing special nuclear material consolidation and facility cleanup operations, this lack of a policy is a concern.

Many items must be repackaged before being put into long-term storage.

DOE has a large number of items, primarily scrap and oxides, that are no longer needed for production and must be placed in long-term storage. However, these items are currently stored in containers that are not suitable for long-term storage, and in some cases, the temporary storage methods (e.g., in gloveboxes or unqualified containers) are unsuitable for storage for significant time periods. In addition, some of the materials represent significant safety and health concerns as well as safeguards risks. Temporary storage methods were not considered a major problem when material was being processed for the weapons program because scrap was consistently being recycled, and several scrap processing operations were active. However, in today's non-production mode, the only processing is in support of decommissioning and material consolidation activities.

Other items require limited reprocessing before long-term storage.

Some items that must be repackaged in preparation for long-term storage are not in a stable form; limited processing is necessary to convert those materials to stable forms for long-term storage. Limited processing is defined as a batch type operation whose input is a discrete item and whose outputs are an item that is slightly modified and a traceable side stream (e.g., waste). An example of limited processing would be firing oxide to obtain a more stable oxide. This operation involves taking a single item, unpackaging it, and placing the material in a furnace. When the material is removed, it is placed in a different container and then remeasured.

These materials should be accurately remeasured in conjunction with repackaging or reprocessing.

It is important that these items have accurate inventory values and that the uncertainties are well characterized before they are placed in long-term storage. However, many of these materials are not well characterized. For example, a recent report from Rocky Flats showed that even similar materials were rarely measured by the same technique, and that the accuracy varied considerably; in some cases, the estimated errors were as high as plus or minus 200 percent. The results showed that the methods used to measure almost 40 percent of the waste and residues are unknown or unrecorded, and therefore no error estimate can be attached to those inventory values. Consequently, additional measurements or remeasurements will be necessary to provide adequate accountability values for scrap items placed in long-term storage.

Policy should be developed to address this need.

To enhance the material accounting program, DOE should develop a policy governing remeasurements. The policy should address remeasurement of items prior to packaging and limited processing. The safety, health, safeguards, and measurement advantages and disadvantages should be considered when developing such a policy.

Remeasurements will inevitably cause inventory differences, which must be evaluated.

There are two basic approaches for measuring reprocessed and/or repackaged materials: (1) measuring after reprocessing and/or repackaging is completed (see Approach 1 on Figure 5), and (2) measuring both before and after limited reprocessing and/or repackaging (see Approach 2 on Figure 5). As shown in Table 3, there are advantages and disadvantages to each approach. In either approach, inventory differences will be generated due to operating losses, inaccuracies in prior measurements, and inherent uncertainties in measurement methods. The second approach may generate a second inventory difference because of the additional measurement step. Each situation must have an independent evaluation to determine the appropriate remeasurement strategy.

Material may be remeasured either before, or both before and after, repackaging or reprocessing.

From a cost and radiation exposure standpoint, the first approach is more desirable, and should be used when there is sufficient confidence that the inventory values are accurate. Although more costly, time consuming, and hazardous, the second approach should be used if the current inventory value for the item is questionable or not defensible and the material is amenable to measurement. In addition, if limited processing is likely to produce inventory differences that cannot be readily explained, then remeasurements should be made. If the second approach is used, every effort must be made to minimize the radiation exposure, and the process should be examined carefully to eliminate any unnecessary time-consuming steps.

The decision on which approach to take will depend on a variety of factors.

In some situations, a combination of the two approaches may be in order to balance health and safety considerations against safeguards considerations. For example, if documentation is insufficient to support the inventory values but the items are expected to contain small amounts of material (and thus are of relatively low concern from the standpoint of safeguards), individual containers being reprocessed and/or repackaged should be evaluated to determine their contribution to the inventory difference. It may be possible to use the information from two or three containers with similar material contents to estimate the magnitude of the probable inventory difference for a larger number of containers of the same material type and configuration. If the difference can be verified as insignificant, it may be appropriate to use the first approach rather than incur the additional radiation exposure and expense of the second approach.

Figure 5. Remeasurement Options

An alternative that is somewhat less costly than the second approach is to enhance material control surveillance for the repackaging operation. Enhanced surveillance could provide assurance that no loss or diversion occurs during the repackaging process. The difference then can be evaluated, and it can be reasonably assumed that any inventory differences occurred before the remeasurement or resulted from the measurement.

No single approach will be valid in every case.

Figure 6 and Table 3 summarize some of the key issues discussed above. No single approach will work for all material types or measurement systems, even within the same facility. The policy and guidelines should recognize that decisions about remeasurements must consider specific material types and measurement systems. However, a clear policy and comprehensive guidelines should assure accurate and consistent measurements across the complex for reprocessed and/or repackaged materials.

4.5 Terminology

Some important terms are not clearly defined.

The review of DOE orders and implementation of material accounting programs across the complex indicates that most of the relevant terms are defined and understood. However, an important term **)** "not amenable to measurement" **)** is not clearly defined, and composition-of-ending inventory (COEI) codes are not used consistently across the complex.

Identification of materials "not amenable to measurement" is inconsistent.

Many facilities consider material "not amenable to measurement" because it is inaccessible, no measurement technology is available, no representative standards are available on site, or health and safety risks limit the ability to measure the material. However, the application of this term is inconsistent across the complex; types of material deemed "not amenable to measurement" at one facility may be measured routinely at another. Further, although required by DOE Order 5633.3B, most facilities in the DOE complex do not document materials that are considered "not amenable to measurement" in their Material Control and Accountability Plans. Even when documented, the references to these materials are often so vague that any material could be included.

For inventory reporting purposes, special nuclear material is classified according to COEI codes, which are used to identify different material forms. The use of COEI codes is not consistent across the complex even for the same material type. Most facilities do not use the standard COEI characterizations to identify special nuclear material inventory and have developed subsets of codes for internal use. This inconsistent usage limits in-depth analysis of inventory data across the complex and impacts program planning. For example, because of the inconsistent

Figure 6. Decision Path for Remeasurements

Table 3. Remeasurement Considerations

TWO OPTIONS FOR REMEASUREMENT	First Approach No remeasurement prior to repackaging	Second Approach Remeasurement prior to repackaging
Advantages	Less radiation exposure Less expense	Provides documentation for resolution of the inventory difference Allows for localization of difference before processing and during processing
Disadvantages	Undefined bias or uncertainty Insufficient documentation for resolution of inventory difference	More costly Generates two inventory differences to track rather than one Delays repackaging Additional radiation exposure during remeasurement
Conditions for Use	Quality measurements and documentation available or Inventory differences are demonstrated to be insignificant for similar materials (Note 1) or Material not amenable to measurement (Note 2)	Material amenable to measurement and Inventory value suspect or Measurement process could generate significant inventory differences that cannot be explained

Notes:

1. Based on the analysis of containers with similar material contents, it may be possible to determine the significance of the contribution to the inventory difference and extend this information to a larger number of containers of the same material type and configuration. If the difference can be verified as insignificant, it may be possible to avoid the extra exposure or expense of the second approach.

2. Enhanced material surveillance may be needed during repackaging to assure that no loss or diversion occurs. The difference that is found can be evaluated assuming it occurred before the repackaging.

Material types are not consistently identified in the Department-wide materials management computer system.

use of the codes, planners cannot rely on data from the DOE-wide Nuclear Materials Management and Safeguards System (NMMSS) to adequately identify the types of materials; as a result, individual facilities must continually devote their limited resources to providing site-specific information. The near-term transition of NMMSS from a mainframe system to a personal computer-based system will make it easier to maintain and update. This transition provides a unique opportunity to concurrently improve the COEI codes to make them more meaningful and useful.

The following actions should be taken to enhance DOE terminology and provide consistency across the complex:

- A policy should be developed specifying explicit criteria for categorizing existing special nuclear material as "difficult to measure" or "not amenable to measurement." These criteria should be developed by cognizant secretarial officers and Security Affairs, with concurrence from the operations offices.

- COEI codes should be revised to accurately reflect the material forms represented in DOE's inventory. In revising the codes, the Department's need for high-level program planning, and the codes' usefulness to the operations offices program managers, should be the primary considerations.

- When the terminology is revised and clarified, facilities should conform to the required usage of the revised COEI codes and the requirement to document material that is "difficult-to-measure" or "not amenable to measurement" in Material Control and Accountability Plans.

These actions will provide consistency across the complex, and will better position DOE to plan for international inspections and decontamination and decommission-ing activities. Further, consistent and accurate data will be needed to better manage and prioritize enhancements to the inventory assurance.

4.6 Shipper/Receiver Transactions

Reconciling shipper and receiver measurements is a longstanding problem throughout the Department.

The inability to close shipper/receiver transactions (those recorded on the DOE/NRC-741 Form) in a timely manner is a longstanding problem across DOE. At one point, there were approximately 800 open transactions. DOE Order 5633.3A, issued in 1993, included a revision allowing for the use of "comparable" measurement methods to close transactions. Since then, the number of open transactions has been decreased significantly. However, there are still approximately 400 open shipper/receiver transactions involving high enriched uranium or plutonium; approximately 250 of those transactions involve high enriched uranium and approximately 150 involve plutonium. A significant number of the open transactions are at the Savannah River Site, and most exceed the required timeframes, with some transactions having remained open for more than twelve years.

The receiving facility often cannot measure the mater-ial in the form in which it was shipped.

One of the primary causes for open transactions is the inability to conduct the required measurement of the shipped item at the receiving facility. In some cases, it is no longer possible to conduct the measurement because the receiving facility does not have suitable equipment, or because the facility cannot process the material into a measurable form. Key processing operations, for example, have been shut down because of operational or environmental, health, and safety concerns. Thus, some of the transactions may never be completed.

The longer the material awaits measurement, the harder it is to reconcile the measured values.

However, prolonged open shipper/receiver transactions can cause problems in accounting for special nuclear material. For example, DOE recently discovered a significant shipper/receiver difference (that is, a difference that cannot be attributed to measurement uncertainty) for a shipment that occurred eight years ago. The investigation for this shipper/receiver difference was complicated by the prolonged time period before the difference was discovered **)** material in the shipment was processed at different time periods **)** and the shipper/receiver difference could not easily be explained.

Some alternatives to shipper/receiver measurements may be acceptable.

The DOE Headquarters Office of Safeguards and Security is actively working with DOE facilities that currently have the major material flows in the complex, such as Pantex, Y-12, and the Savannah River Site, to relieve the burden of performing 100-percent receipt verification measurements. They have recommended that facilities include in shipper/receiver agreements the use of advanced seals, which provide higher levels of assurance to the integrity of the material in transit. Receipt measurements of statistical samples of the materials are also being considered.

Resolving these problems requires a coordinated effort at all levels of the Department.

Although progress is being made, it is important to devote additional attention to open transactions. Longstanding open transactions cannot be resolved by individual facilities; resolution requires the cooperation and attention of Headquarters, as well as both the shipping and the receiving facilities. Consequently, enhancing this aspect of the material accounting program will require a Headquarters-based effort. Headquarters elements, including the cognizant secretarial officers and Security Affairs, should lead an effort to evaluate the closure of open transactions. Specifically, Headquarters, in coordination with the respective operations office, should review all open transactions and complete transactions for which defensible values are documented. Using this approach, a large percentage of the open transactions could be closed in a timely manner. This approach may result in some short-term problems, and possibly investigations, if additional discrepancies are identified. However, additional delays in resolving these open transactions will only worsen the situation. Timely review and closure will minimize difficulties in collecting the data necessary to conduct effective investigations and resolve the discrepancies.

5.0 COORDINATED AND SYSTEMATIC APPROACH TO ENHANCING INVENTORY ASSURANCE

Enhancing inventory assurance will require a systematic, coordinated effort.

As discussed in Section 2, many of the values in DOE inventory records are based on inaccurate measurements, are estimated, or cannot be defended because of lack of appropriate records. Fissile inventory assurance must be enhanced to address concerns about safeguards, international standards, safety, health, operations, decontamination, and decommissioning concerns, as outlined in Section 3. To enhance fissile inventory assurance, it is essential that DOE meet its requirements for ensuring that all special nuclear material, including holdup, is reflected on the inventory records at measured values.

Many facilities have not devoted adequate attention to inventory values.

DOE is very much aware of the problems with the current inventory values; some facilities have already begun to obtain accurate inventory values for their materials. However, the efforts to date have been piecemeal, and the results have not been impressive. Although material control and accountability groups at some facilities have made sincere efforts, few have made significant progress in reducing the unmeasured or inadequately measured inventory, and progress has been slow even at facilities that have initiated measurement programs. Some of the lack of progress can be attributed to safety and health concerns and to the shutdown of processing operations, which makes measurements difficult or impossible. However, a lack of priority, emphasis, commitment, and coordination has also contributed to the current situation.

The amount and variety of materials involved contribute to the magnitude of the problem.

The individual enhancements identified in Section 4 will go a long way toward addressing some of the most significant concerns. However, the magnitude of the problem is immense, and the obstacles to conducting the needed measurements are significant. Measuring all materials that do not have accurate accountability values with today's accurate measurement equipment and techniques will be expensive and time-consuming. Some types of materials will require processing into a measurable form before more accurate measurements are possible, and some facilities are not presently able to resume even limited processing. In addition, it will be necessary to make tradeoffs between competing priorities (e.g., conducting measurements necessary to obtain defensible values, while minimizing workers' exposure to radiation). Further, there are a number of complex issues to resolve, including the identification of optimal measurement techniques and the best containers for long-term storage.

Inventory problems that have developed over fifty years of operations are not easily solved.

There are no easy or quick solutions to problems that have grown over fifty years of operations. To address the inventory assurance concerns, it will be necessary to adopt a systematic, coordinated, and complex-wide approach to material accounting issues. Decisions on enhancing the material accounting program must be made carefully, weighing the expected benefits against the costs for each type of material and site-specific situation. Given the amounts of material and the wide variety of types of material, the problems are too big to address in one step; it will be necessary to prioritize the material types and address the most significant problems first. To address these concerns effectively, a sustained and coordinated effort will be needed over a number of years.

A Headquarters-level steering group would help provide consistent guidance.

Taken together, the results of this study indicate a need for a comprehensive, DOE-wide program with Headquarters-level direction and guidance. To provide consistent and effective Headquarters direction, DOE should establish a steering group, consisting of representatives from Headquarters program offices, the Headquarters Office of Safeguards and Security, operations offices, and DOE facilities. The steering group could be modeled after the DOE Materials Management Executive Committee, which was active during the period when DOE was producing nuclear weapons and faced shortages in some types of materials. The Materials Management Executive Committee analyzed competing priorities and provided direction to individual facilities, consistent with DOE's overall objectives.

The overall mission of the steering group should be to provide consistent and coordinated direction and guidance to the DOE material control and accountability community. The specific responsibilities of the steering group should include:

- Monitoring the efforts of program offices, operations offices, and facilities to assure that they are coordinated and consistent with DOE's goals and priorities

- Being the advocate at Headquarters for the material control and accountability community, assuring that material accounting issues are given appropriate priority and emphasis in the DOE planning process

- Representing material control and accountability interests when facilities are attempting to resume operations necessary to convert special nuclear material to forms that are safer, more stable, or more measurable

- Prioritizing and monitoring DOE's efforts to measure material and assuring that special nuclear materials are reflected on the inventory records with defensible inventory values

- Reviewing and developing policies needed to reflect the measurements and inventory issues that will be encountered during bilateral and IAEA inspections at DOE facilities

- Providing guidance to the field on analyzing the costs and benefits of accurately measuring all of their materials, and emphasizing the need to conduct new measurements whenever the cost/benefit analyses show it to be feasible

- Directing studies of facility needs and equipment usage, promoting sharing of resources, and resolving competing priorities

- Coordinating and guiding studies on the effectiveness of safeguards at facilities with significant quantities of holdup
- Coordinating and guiding efforts to standardize measurement methods, containers, and software
- Coordinating and monitoring other specific actions identified in Section 4 (including development of policy governing remeasurements, clarifying the terminology and codes, and resolving the open shipper/receiver transactions).

The steering group should contain representatives from the field, as well as Headquarters.

The steering group approach, if properly implemented, will ensure coordination, consistency, and cost effectiveness across the complex. It provides a mechanism for the materials control and accountability community to prioritize their efforts on a DOE-wide basis considering all DOE objectives (including safeguards, international and bilateral inspections, environment, safety, health, decontamination, and decommissioning) and develop practical and cost-effective approaches to complex problems. However, for such an approach to work, the steering group must have representation from Headquarters, operations offices, and DOE facilities. Equally important, the steering group must have management support to implement strategies that are deemed best from the overall DOE perspective, even though those strategies may not be optimal for individual facilities.

Options must be identified and evaluated systematically.

Regardless of whether a steering group is established, DOE facilities should systematically evaluate options for enhancing material inventory assurance. Table 4 identifies the options that should be considered and criteria that should be considered. Appendix F provides additional information on evaluating options for enhancing fissile inventory assurance. If established, a steering group could assist facilities in conducting such analyses and assure that they are conducted in a uniform manner across the complex.

Materials should be prioritized to promote efficient actions.

One of the key activities of the steering group, if established, should be to set priorities for material types, and to enable facilities to conduct the necessary measurements. Currently, a number of materials require attention in the near term because of safety and health considerations, as well as safeguards concerns. DOE has a unique opportunity to increase its fissile inventory assurance and

Table 4. Options and Criteria

OPTIONS FOR ENHANCING FISSILE INVENTORY ASSURANCE 1. Status Quo 2. Measure Material 3. Ship Materials 4. Ship Instrumentation 5. Convert Material
EVALUATION CRITERIA **Safeguards Effectiveness**. Does the option provide control and accountability of special nuclear material? **Timeliness**. Does the option provide the potential for the timely reduction of unmeasured inventory? **Cost**. Is the cost of implementing the option reasonable for the return on investment? **Health and Safety**. Does the implementation of the option pose any significant problems to the general well-being of plant workers and the public?

address environmental, safety, and health hazards through limited processing and special nuclear material consolidation activities.

Limited processing, while risky, involves less risk than continuing with the status quo.

A certain amount of effort will be needed to reestablish limited processing. Some of the required processes have been shut down for several years and will require refurbishment before resuming operations; others were designed with processing throughputs that exceed current needs and generate waste streams that do not comply with today's regulations. DOE has been evaluating various alternatives for processing, but only minimal high enriched uranium processing and no plutonium processing is being conducted. Among the most important contributions that a steering group could make are supporting facilities' attempts to restart some of the needed processes and implementing the long-term storage configurations, as recommended by the Nuclear Materials Disposition Team. Although a restart of operations inevitably involves some risks, it is important to consider that the status quo may result in a higher and increasing level of risk, as demonstrated by the degradation of containers containing plutonium oxides, which has resulted in an increasing number of significant incidents (e.g., overpressurization of containers).

A preliminary list of prioritized activities is provided.

Table 5 provides a preliminary set of prioritized near-term activities that should be considered for high enriched uranium and plutonium. The steering group should review and modify this preliminary list as necessary to reflect additional information and other viewpoints. When fully developed and validated, such a list could serve as the basis for prioritizing resources and instituting limited processing operations. Similar strategies should be used even if the steering group concept is not implemented.

Table 5. Preliminary Set of Near-Term Actions

Potential Near-Term Actions to Improve Fissile Inventory Assurance	
	High Enriched Uranium Activities
(1)	Continue consolidation of metal (Y-12 and Savannah River Site).
(2)	Process incinerator ash and combustibles (Y-12).
(3)	Reduce inventory levels of low concentration uranium nitrate solutions (Y-12).
(4)	Commence dissolution of other uranium scrap forms and process to a more concentrated, measurable form (Y-12).
(5)	Initiate solvent extraction activities and concentrate material to a more measurable form (Y-12).
(6)	Process the uranyl nitrate solution at the Rocky Flats Plant and the Savannah River Site to a more measurable form and ship it to Y-12.
(7)	Recover material held up in decontamination and decommissioning facilities for the Environmental Restoration Program (K-25, Idaho, Portsmouth).
	Plutonium Activities
(1)	Remove and stabilize the unstable oxide from the glovebox storage positions (Rocky Flats Plant).
(2)	Unpackage, calcine at 1000 ^{o}C, safely repackage, and remeasure the scrap oxides (Rocky Flats, Savannah River, Los Alamos, Lawrence Livermore).
(3)	Maintain fissile inventory assurance during repackaging of plutonium metal (all facilities with plutonium metal).
(3)	Convert plutonium nitrate solutions to a stable oxide (Rocky Flats, Savannah River, Hanford).
(4)	Process incinerator ash, sand, slag, and crucible and other plutonium process residues to a stable oxide. (Rocky Flats, Savannah River, Hanford).
(5)	Conduct a plutonium holdup measurement and evaluation program, and recover material from areas with significant accumulations or areas that have significant environment, safety, and health concerns (Rocky Flats, Savannah River, Hanford).
(6)	Recover material held up in decontamination and decommissioning facilities for the Environmental Restoration Program (Hanford, Rocky Flats).

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6.0 CONCLUSIONS

Questionable inventory values present a large problem.

Many of the values in DOE inventory records are based on inaccurate measurements, are estimated, or cannot be defended because of lack of appropriate records. The magnitude of the problem is significant and widespread, but is limited primarily to scrap, oxides, and holdup.

Although material is not generally at risk, accurate values are needed to support many Departmental initiatives.

The risk of theft or diversion of strategic quantities of special nuclear material is low at most DOE facilities because of the other controls in place. However, an accurate inventory of special nuclear materials is necessary to provide assurance that material has not been stolen or diverted. In some instances, the inventory and measurement programs cannot provide reliable information. In many cases, DOE does not have sufficiently accurate information on hand about its special nuclear materials inventories to meet international standards, or to allow DOE facilities to properly plan for decontamination and decommissioning activities. DOE must adequately explain, analyze, and investigate inventory differences to assure that the United States does not appear to violate international treaties or standards, and maintains credibility with the American public.

The benefits of getting better values must be weighed against the costs.

Measurement technology has advanced to the point where it is now feasible to accurately measure most of the special nuclear material at DOE facilities. Additional measurements should be conducted to increase the confidence in the inventory to improve the safeguards program and prepare for international inspections and facility decontamination. However, additional measurements are costly and potentially hazardous; decisions to conduct them must be based on a careful analysis of the potential costs and benefits.

A systematic, coordinated, Department-wide effort is needed.

Although some progress has been made, the efforts to date have been somewhat fragmented. Few facilities have made significant progress in reducing the unmeasured or inadequately measured inventory because equipment is not available, necessary processing operations are shut down, or insufficient resources or low priority have been given to addressing this situation. Given the amounts of material and the wide variety of types of material, it will be necessary to prioritize the material types and address the most significant problems first. To address these concerns effectively, a sustained and coordinated effort will be needed. To provide consistent and effective Headquarters direction, DOE should establish a steering group, consisting of representatives from Headquarters program offices, the Headquarters Office of Safeguards and Security, operations offices, and DOE facilities.

Some near-term and long-term actions are proposed.

Although there are no easy or quick solutions, there are some actions that can be taken to enhance the DOE's special nuclear material inventory program. Some of these actions can be implemented in the near term, with little program impact or cost; others will require more time and resources but may have long-term benefits that outweigh the costs. The following actions provide the basis for enhancing the material accounting program:

- To address concerns associated with unmeasured inventory values, DOE should assure that all such materials are adequately measured, have defensible values, and are entered in the accountability records.

- Holdup requires attention and scrutiny in all aspects, including physical security and material control, as well as increased measurement accuracy. All material in holdup should be adequately measured, or estimated, and entered in the accountability records.

- DOE Headquarters should lead a complex-wide review of the availability of measurement equipment and facility needs. DOE Headquarters could coordinate the measurement needs of individual facilities with underutilized resources (including both unused equipment and trained and qualified personnel) available at other facilities.

- Efforts to standardize NDA measurement systems and techniques across the DOE complex should be increased. Containers for uranium and plutonium oxide, weapons components, and scrap should be standardized to meet both measurements and long-term storage requirements.

- NDA software should be controlled by a single point within the DOE, and the most current source code listings and compiled codes should be available to all DOE facilities.

- DOE should develop a policy governing remeasurements. The policy should address remeasurement of items prior to packaging and limited processing.

- A coordinated approach to international and bilateral inspections should be developed and adopted.

- A policy for the classification of existing special nuclear material as "not amenable to measurement" should be developed.

- COEI codes should be revised to accurately reflect the material forms representative of DOE's inventory.

- Headquarters elements, including the cognizant secretarial officers and Security Affairs, should lead an effort to evaluate the closure of open transactions.

APPENDIX A
FACTORS AFFECTING THE DOE MEASUREMENTS PROGRAM

A number of events and trends prompted the need to examine the level of confidence the Department of Energy (DOE) has in its inventory values for special nuclear material. These events are occurring on the national and international level and will affect DOE policies for special nuclear material control and accountability (MC&A). The following overview discusses some of the factors that were considered when this study was commissioned.

Security Evaluations findings have identified unmeasured inventories, and measurement systems and physical inventory practices that are not in compliance with DOE orders.

During its safeguards and security inspections, the Office of the Deputy Assistant Secretary for Security Evaluations has documented several deficiencies at DOE facilities in both physical inventory and measurement systems. Physical inventory deficiencies include the failure to take simultaneous physical inventories annually for all material balance areas, inadequate sampling programs for physical inventory, significant quantities of unmeasured material on inventory, and deficient tamper indicating device programs with deficient confirmation measurement systems. The findings concerning measurement systems include systems that were not calibrated, initially qualified, or under an ongoing measurement control program, and material that was not independently measured by the shipper and receiver. These findings directly affect fissile material inventory assurance and provide insight into future potential problems.

The DOE openness initiative requires DOE to release information about its inventory of plutonium and high enriched uranium.

The Secretary of Energy, supporting the

President's goal of openness in the government and the nonproliferation and export control policy, outlined her Openness Initiative in a December 7, 1993, press conference. At a press conference on June 27, 1994, the Secretary released previously classified data such as the physical inventories and inventory differences at several DOE facilities, with the exception of the DOE fissile inventory at the Pantex facility. These openness initiatives could diminish the public trust in the DOE's fissile inventory. Increasing the awareness of the general public has led to misunderstandings in the past. Thus, there is a need for clear communication between DOE and the general public. Although processing activities have ceased, there will be additional inventory differences.

The existing quantity of special nuclear material is excessive in relation to United States defense needs. Planning is now under way for the ultimate disposition of this excess material, but in the interim it must be stored safely and securely.

Commensurate with the passing of the Cold War, there is no longer a need for large quantities of special nuclear materials as part of the weapons stockpile. The exact defense program requirements have not yet been determined, but certain quantities of material are excess and must be prepared for ultimate disposition. In some cases, limited processing must be completed before interim disposition is possible. The National Academy of Sciences (NAS) stated:

> "The existence of this surplus material constitutes a clear and present danger to nations and international security. None of the options yet identified for managing this material can eliminate this danger; all they can do is to reduce the risks. Moreover, none of the options for long-term disposition of excess weapons plutonium can be expected to substantially reduce the inventories of excess plutonium from nuclear weapons for at least a decade." (<u>Management and Disposition of Excess Weapons Plutonium</u>. National Academy of Sciences, 1994, p. 1)

The NAS also suggests:

> "Three key security objectives: 1. to minimize the risk that either weapons or fissile materials could be obtained by unauthorized parties; 2. to minimize the risk that weapons or fissile materials could be reintroduced into the arsenals from which they came, thereby halting or reversing the arms reduction process; 3. to strengthen the national and international arms control mechanisms and incentives designed to ensure continued arms reductions and prevent the spread of nuclear weapons." (<u>Management and Disposition of Excess Weapons Plutonium</u>, National Academy of Sciences, 1994, p. 3)

The identification and quantification of excess special nuclear material is an essential step in disposition activities.

Special nuclear material will be made available for inspection by both the International Atomic Energy Agency (IAEA) and Russia.

Under bilateral and international agreements, weapons complex facilities will be open for inspections. This will create a new set of regulations with which DOE facilities must comply in order to demonstrate fissile inventory assurance. International inspection teams will use different measurement equipment, methods, and data analysis techniques that will result in differences when compared to DOE's current special nuclear material inventory values. The inability to explain, analyze, and investigate these differences could create the appearance of not complying with international treaties. This was highlighted by Wolfgang Panofsky:

> "As the issues in accountability are defined and problems are solved, the groundwork is laid for the political efforts to move forward with success. Only as the measurement issues are resolved can the sites be submitted to outside verification with confidence. The prospects of measurements which cannot be verified cast a shadow across the shining

example the United States must provide to keep the dismantlement and disposition of weapons an ongoing process worldwide." (Wolfgang K. H. Panofsky, "Safeguarding the Ingredients For Making Nuclear Weapons," Science and Technology, Spring 1994).

Thus, DOE facilities must be prepared to demonstrate fissile inventory assurance and comply with international and bilateral agreements.

A disposition team has been established to evaluate options for disposal of excess special nuclear material and to provide assurance that materials are safe for interim and long-term storage.

The Secretary of Energy established the Nuclear Materials Disposition Office in January 1994 for developing Departmental recommendations and for directing implementation of decisions concerning disposition of excess special nuclear material. The Office's objective is to provide for safe, secure, and environmentally sound control, storage, and ultimate disposition of surplus special nuclear material. Characterization of special nuclear material including the determination of inventory quantities, is an important, integral component of disposition activities. This was recently emphasized when the Stockholm International Peace Research Institute wrote:

> "Precise material inventories will be required for managing the storage, disposal or recycling of the materials, and for providing confidence that they are protected and will not again become available for making nuclear weapons." (World Inventory of Plutonium and Highly Enriched Uranium, 1992, p. 4)

Organizational responsibility for some existing DOE facilities is being transferred from Defense Programs (DP) to Environmental Management (EM).

As facilities are transferred to EM for decontamination, decommissioning, and ultimate disposition of special nuclear material, the quantity of special nuclear material must be known and adequate safeguards must be in place. EM activities must include provisions for environment, safety and health, criticality safety, the "as low as reasonably achievable" (ALARA) principle, conduct of operations, and Occupational Safety and Health Administration requirements. The environmental restoration program requires a proactive MC&A program. The information MC&A should have, or be able to obtain, will be invaluable to the EM effort. Only as holdup values are established can cleanup efforts continue effectively and meet the regulatory requirements.

Unmeasured and/or unaccounted-for holdup of special nuclear material is an operational concern at DOE facilities.

Facilities treat holdup differently throughout the DOE complex. Holdup may be measured, estimated, or simply not included in the physical inventory. Special nuclear material holdup in equipment is an ongoing concern for cleanup activities, international inspections, and ultimate material disposition. The decay of plutonium in process holdup can increase personnel exposures during cleanup activities. Determining measured values for holdup and implementing proper accountability will increase fissile inventory assurance and support disposition activities.

Policy changes are affecting special nuclear material accountability.

MC&A policy changes can affect fissile inventory assurance. Extended inventory frequencies can lead to reduced personnel radiation exposure, but may conflict with the frequencies required by the IAEA. MC&A policy changes regarding shipper/receiver differences have helped in reducing the backlog of open shipment transactions. DOE policy now permits the use of comparable measurement equipment to perform confirmatory measurements of receipts and achieve safeguards closure of special nuclear material shipments. The current environment within the DOE suggests that additional MC&A

policy changes will be necessary to increase fissile inventory assurance.

Plutonium vulnerability assessment team activities may result in repackaging or limited processing of materials.

The team will identify environment, safety, and health vulnerabilities that will impact the overall inventory assurance of special nuclear material, as well as existing compensatory measures. Facilities must then identify near- and long-term upgrades to correct deficiencies. An additional concern is the type of re-packaging needed for long-term plutonium storage, and scrap forms of special nuclear material that can be pyrophoric. Plutonium vulnerability assessment team activities will further impact fissile inventory assurance of special nuclear material by identifying material that must be processed into a stable form for long-term storage. Once the material and process have been identified, adequate funding must be provided to assure that activities are accomplished.

The NAS has expressed concerns with the environment, safety, and health aspects of materials such as scrap:

> "While the amount of plutonium in these forms is smaller than the amount in pits that will result from arms reductions, the volume is much greater, the variety of forms of material is wide, and the environment, safety, and health (ES&H) risks are substantial for some forms. Even characterizing the constituents of these materials accurately is difficult."

Remeasurement and/or measurement after limited processing of materials creates variations due to operating losses, inaccuracies in prior measurements, and uncertainties inherent in measurement methods.

These are numerous concerns throughout the DOE complex regarding material in storage and material left in process equipment and lines that were abruptly shut down. In a recent review of activities at the Rocky Flats Plant, the Government Accounting Office stated that:

> "...it appears that any alternative DOE selects to remove the residues will likely require the processing of residues in some manner and at considerable costs for upgrading facilities. Moreover, considerable time will be necessary to complete the actions required." (GAO/RCED-92-219, Removing Plutonium Residues From Rocky Flats Will be Difficult and Costly, September 1992).

Additional processing will require use of chemicals whose release to the environment must now be reported. Executive Order 12856 requires federal facilities to report chemical inventories and releases. The Order also sets a goal of 50 percent reduction in releases. Achieving this goal is in direct conflict with projected DOE processing activities to process and stabilize scrap. This could delay processing, jeopardize DOE credibility, and degrade the confidence the public has in the DOE's ability to manage special nuclear material.

Remeasurement or limited processing will occur in an environment that is dramatically changed from the weapons production era. Providing fissile inventory assurance in this era is one of the most important objectives for the DOE.

As a whole, DOE is experiencing reduced budgets and increased emphasis on cost-effective operations.

DOE and its operating contractors are being required to do more with less funding. Although budget reductions could adversely impact inventory assurance, assurance must be achieved despite fiscal constraints. The new MC&A requirements being implemented to meet bilateral and international inspection requirements will increase the level of effort and thus the funding demands for MC&A.

The special nuclear material inventory is only one part of an integrated safeguards system; physical security measures are being reduced as a result of changing budgets and operational requirements.

The need to rely on more than material accounting to prevent theft and/or diversion has also been recognized by the National Academy of Sciences:

> "...it is doubtful that material accounting alone will be able to guarantee that diversion of enough plutonium to make a bomb could be detected within days. It will probably not be possible to achieve the 'stored weapons standard' of accounting when dealing with complex, multi-stage processing of plutonium in bulk form. Therefore, in addition to stringent material accounting, there should be extensive containment, surveillance, and security measures to ensure that no plutonium leaves the site without authorization."
>
> (Management and Disposition of Excess Weapons Plutonium, National Academy of Sciences, 1994, p. 168)

Many DOE facilities are making significant changes in their physical security posture as a result of changing operational requirements and the need to increase efficiency and reduce costs. Physical security measures have often been cited as a compensating factor when DOE facilities made decisions about the acceptability of less-than-optimal measurements and inventory values.

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APPENDIX B
SCOPE, CONDUCT, AND TERMINOLOGY

The data collection efforts focused on determining how facilities address holdup, characterizing difficult-to-measure material, and developing future plans for measurement activities. The information collected for this study helped identify complex-wide trends and potential areas for improvements.

The Security Evaluations special study team included people with expertise in measurement technology, facility operations, inspections of Department of Energy (DOE) facilities, and international safeguards. Experts in measurements technology from Los Alamos National Laboratory provided input to the study and provided comments on preliminary drafts. Safeguards personnel at DOE operations offices and their site contractors, as well as measurement experts, were contacted, and applicable measurement systems were identified. The team received many valuable comments and suggestions from DOE operations offices and facilities representatives.

A draft of this report was distributed for review and comment to operations office managers, safeguards and security directors, program offices, and technical experts. The Security Evaluations special study team considered all comments carefully and made revisions reflecting the consensus of the community.

For the purpose of analysis, the September 1993 DOE special nuclear material inventory data were obtained from the central database for all DOE material inventory and transaction data, the Nuclear Materials Management and Safeguards System (NMMSS). In the context of this study, "special nuclear material" refers to plutonium reported as material type codes 51 to 57 (all plutonium) and high enriched uranium reported as material type codes 34 to 39 (uranium enriched to greater than 20 percent U-235). To analyze the data, the study used an existing database manager developed by Defense Programs called the Inventory Management Information System (IMIS), which allows manipulation of the NMMSS data and permits the user to search and sort, create reports and graphs, and export NMMSS data to other software applications.

"Scrap" is traditionally defined as material that is not product and from which usable special nuclear material is determined to be economically feasible to recover. For the purposes of this study, impure oxides are included in the list of traditional scrap materials.

As used in this study, the term "material accounting program" includes accountability systems, physical inventories, and measurements programs.

"Inaccurate," as used in this study, refers to differences between the accountability value and the true value. It encompasses both random and systematic errors in the measurement process.

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APPENDIX C
INVENTORY DIFFERENCES

This appendix provides additional detail on inventory differences. It includes a comparison of the inventory differences for plutonium and uranium as a percentage of total inventory. It also provides a more detailed breakdown of the inventory differences by category of material and time period (pre-1988, when the DOE was producing and processing significant quantities of special nuclear material, and post-1988, when most production activities had effectively been halted).

Inventory Differences as a Percentage of Total Inventory

The data show that the plutonium inventory difference is significantly greater than the high enriched uranium inventory difference as a percent of the total production (considering only the unclassified quantities). The plutonium inventory difference is 2.64 percent of the total amount of plutonium produced to date (2,700 kg out of 90.6 metric tons), while the high enriched uranium inventory difference is 0.13 percent (1,316 kg out of 994 metric tons). The greater plutonium inventory difference was expected because of the nature of the plutonium production process.

Inventory Differences by Time Period

Figure C-1 shows inventory differences by facility and time period (pre-1988, when the DOE was producing and processing significant quantities of special nuclear material, and post-1988, when most production activities had effectively been halted) for uranium. Figure C-2 and Table C-1 show similar data for plutonium. These figures indicate that the inventory differences since 1988 are significantly smaller than in previous years. This reflects both the decrease in processing and improvements in the material accounting program.

Table C-1. Plutonium Inventory Difference Pre- and Post-1988

FACILITY	INVENTORY DIFFERENCE		
	PRE-1988	POST-1988	CUMULATIVE
Argonne National Laboratory - West (ANL-W)	-3.4	0	-3.4
Hanford	1263.1	1.9	1265
Idaho National Engineering Laboratory (INEL)	-5.6	0	-5.6
Los Alamos National Laboratory (LANL)	72.4	-22.9	49.5
Lawrence Livermore National Laboratory (LLNL)	3.5	1.8	5.3
Savannah River (SR)	188.8	45.2	234
Rocky Flats (RF)	1205.7	-14.7	1191

APPENDIX D
MEASUREMENT TECHNOLOGY

This appendix provides general background information about measurement technology. It provides technical information about some of the issues raised in the main report, and may be useful for persons who are not familiar with some of the technical aspects of measurements.

The discussion focuses on the characteristics of uranium and plutonium that provide the means for the nondestructive assay (NDA) measurements. The focus is on NDA because most of the special nuclear material in the Department of Energy complex is located at facilities that do not have active processes and therefore have difficulty in obtaining representative samples of containers. In addition, much of the material in the complex is in a form that is not amenable to sampling and destructive analysis. NDA techniques that are appropriate for inhomogeneous materials previously encased in containment, such as waste drums, product and scrap oxide, and off-spec metal, are addressed.

The development of NDA measurement methods for nuclear materials dates back to the dawn of the nuclear era. It was a natural step to use the characteristic radiations emitted by most special nuclear materials to detect and quantitatively measure their presence. The main motivation for the development of NDA was the need to reduce the uncertainties in measurements of fissile material present in mixtures and in such configurations as scrap and waste, which are difficult or impossible to measure with conventional destructive analysis techniques.

Gamma Measurements

Gamma measurements are used for quantitative determination of special nuclear material and for determination of the isotopic composition of uranium and plutonium. This section describes the principles of gamma measurements, the use of segmented gamma scanning for quantitative determinations, and measurements of gamma isotopic distribution.

Principles of Gamma Measurements. Gamma rays are a form of high-energy electromagnetic radiation, similar to radio waves and visible light. Special nuclear material emits gamma rays during its radioactive decay. The energy and intensity of the emitted gamma rays are different for each specific isotope. These characteristic gamma rays for each isotope are used to determine the presence and amount of the isotope being examined. For example, the U-235 isotope of uranium decays by emitting an alpha particle to an excited state of the thorium isotope Th-231, then emitting a 186 keV gamma ray 57 percent of the time. The production rate of 186 keV gamma rays is directly proportional to the amount of U-235 in an item. Similarly, one of the gamma ray energies used to identify Pu-239 has an energy of 414 keV.

However, the measurement of special nuclear material items is complicated by many factors. First, not all of the gamma rays escape from the container, so a mathematical correction factor is needed to account for this gamma ray attenuation. Second, only a fraction of the gamma rays escaping the container is detected, so a correction for detector-sample geometry is required. Finally, other gamma rays may interfere with the detection of the gamma ray of interest. Sophisticated computer codes are needed to distinguish the energy region for the isotope in question from other isotopes that may be present in the item.

Segmented Gamma Scanner System (SGS). The SGS is one of the most widely used NDA instruments (Figure D-1). The technology became commercially available in 1980. The SGS measures the gamma radiation emitted from a container to quantify the special nuclear material content. For measurements of plutonium, the SGS measures only Pu-239. Additional measurements are necessary to determine total plutonium content. The SGS addresses two major problems encountered in NDA: location of special nuclear material within the container, and self-attenuation. The sample is rotated, translated, and interrogated with gamma rays of known energy (typically, those emitted by Se-75 or Ba-133) to address these problems.

Many technological advances have fostered improvements in the original equipment and software. For example, waste drum assay systems have improved considerably (Figure D-2). Currently, many facilities in the DOE complex use an SGS system, but the systems differ in measurement capability and in certain hardware and software. If the same container were assayed on five different systems, five different readings would result; these variations could cause measurement differences if not adequately addressed by the measurement control program.

Gamma Isotopic Analysis. The principal application of plutonium isotopic measurements is to support other NDA methods, notably calorimetry and neutron coincidence counting. A measurement of isotopic composition is required to convert the coincidence counter response to plutonium mass. Calorimetry uses the isotopic information to calculate the specific power of a sample from the measured isotopic fractions and the known specific power for each isotope.

Currently, very different computer software codes are used for analyzing gamma ray isotopic distribution in the DOE complex. Three of these codes - FRAM (version 2.1), MGA (version 1.03) which is used by the International Atomic Energy Agency (IAEA), and TRIFID (version 5.8.9.1) - were compared at the Los Alamos Plutonium Facility under carefully controlled conditions. The three codes differ in the energy ranges analyzed, the number of detectors used, and peak area and isotopic ratio calculational methods. The results indicated that all three codes are essentially unbiased for Pu effective and Pu-240 effective for measurements of low burnup (approximately 6% Pu-240) material. At increasingly higher levels of Pu-240, FRAM gradually meets and exceeds the precision and accuracy of MGA for the measurement of effective specific power.

The comparison data suggest that for the assay of pure, homogenous, weapons grade (6% Pu-240) plutonium oxide, MGA delivers the best precision and accuracy for the measurement of effective specific power and Pu-240 effective.

A study (LA-UR-93-2848) concluded that the measurement of the same material by different isotopic codes for both calorimetry and neutron counting would generate different values for the special nuclear material. While the differences would probably not be statistically significant for pure, homogenous, weapons grade plutonium oxide, the use of different codes could generate significant differences for special nuclear materials with varying Pu-240 isotopic fractions.

The major source of uncertainty for both calorimetric assay and neutron coincidence counting often lies in the determination of the plutonium isotopic distribution as determined by gamma ray spectroscopy. Thus, the selection of the appropriate isotopic code for the material types being measured is important for accurate calorimetric assay and neutron coincidence counting.

Figure D-1. Gamma-Ray Scanner for 55-Gallon Drums

Figure D-2. Waste Drum Assay System

Neutron Coincidence Measurements

Neutron coincidence counting plays an important role in determining the mass of fissile material in nuclear safeguards. The principle is simple: the mass of special nuclear material is proportional to the spontaneous fission rate. During the fission process, multiple neutrons are emitted within a short time frame, that is, "in coincidence." The number of neutrons emitted in coincidence is directly proportional to the amount of special nuclear material.

Principles of Neutron Measurements. Most neutron measurements are made using coincidence counting techniques because of the ability to discriminate between neutrons produced from fissions and those produced in (α,n) reactions. This feature allows passive assay of plutonium with high spontaneous fission rates (for example, Pu-240), even in the presence of significant (α,n) reaction rates and room background. Neutrons from spontaneous fission or induced fission are emitted essentially simultaneously, and the neutron coincidence circuitry is set up to measure only those simultaneous events (Figure D-3).

Active versus Passive. Passive neutron coincidence counting quantifies the neutrons emitted by a sample. When the equipment is properly calibrated, the emitted neutrons are directly proportional to the mass of special nuclear material. If there are not enough naturally produced passive neutrons to perform measurements, then neutrons can be induced by active techniques. In active techniques, the sample is exposed to an external source of neutrons (e.g.. Cf-252 or AmLi). The emitted neutrons are then used to calculate the quantity of special nuclear material.

Passive techniques are desirable for the measurement of scrap, waste, and residues because passive assays are inherently less complex. However, active techniques should be used if:

- The substance emits no passive neutrons, or the spontaneous radiation cannot be distinguished from background radiation.

- Spontaneous emissions are not intense enough for precise assay within a reasonable amount of time. (Active NDA can be used to increase levels of emitted radiation to overcome most intensity problems.)

Active Well Coincidence Counter/Multiplicity Counters. Active well coincidence counters (AWCC) are used to measure the special nuclear material content of bulk high enriched uranium. The normal AWCC technique is to induce fissions in a sample with neutrons from AmLi isotopic neutron sources and to count the coincident neutrons from the fissions with coincidence circuity. When the equipment is properly calibrated, the coincidence count rate determines the U-235 content of the sample (LA-12224-MS).

Active neutron multiplicity counting is a new NDA technique for the assay of bulk high enriched uranium. It is currently being field tested at the Y-12 Plant. Based on studies in 1992 using active neutron multiplicity assay techniques on bulk uranium samples using a conventional AWCC with multiplicity electronics and software, the assay precision is about 1 percent RSD for a 1,000-second counting period for 4 kg or more of U-235 metal.

The plutonium multiplicity counter is coming into use in several DOE facilities. It is a highly efficient neutron counter designed for measuring the multiplicity of the neutron emission from both spontaneous fission and induced-fission reactions in plutonium and uranium. There are currently two field tests for this technique: Japan and Lawrence Livermore National Laboratory. To date, most of the testing for the multiplicity counter has been accomplished by the IAEA in Japan.

Figure D-3. Neutron Multiplicity Counter for Special Nuclear Materials Verification

Developed to measure impure plutonium and mixed-oxide (MOX) scrap materials, the plutonium multiplicity counter is applied to impure plutonium containers that range from a few tens of grams to several kilograms of high-burnup plutonium.

Shuffler. A shuffler is an NDA instrument used to determine the fissile content of materials (Figure D-4). It places an isotopic source of neutrons near the container to induce fissions, withdraws the source, and counts the delayed neutrons. In a typical assay, a Cf-252 source is used to induce the fissions. The Cf-252 shuffler is used to assay fissile material contained in 55-gallon drums and other containers. It is used for scrap and waste as well as product streams. During irradiation, flux monitors measure the thermal and fast components of the neutron field. These measurements are used to correct for matrix effects. After irradiation, the Cf-252 source is rapidly withdrawn to a shielded area, and delayed neutrons are counted with a high-efficiency detection system that surrounds the sample. The delayed-neutron response is related to the total mass of fissile material (LA-UR-93-2427). The source is shuffled until a sufficient number of delayed neutrons have been counted.

The shuffler technique is generally applied to difficult assay cases; for example, if:

- The amount of material present is small (100 milligrams to 1 gram for a cadmium lined cavity and 1 to 10 milligrams if the liner is removed), and thus does not spontaneously emit sufficient neutrons.

- The amount of material is below the AWCC level of sensitivity.

- The fissile amount may be fairly large, but the rate of spontaneous emitted neutrons is low.

- The highest assay precision is desired (favoring a shuffler over an active well), even if the material is inhomogeneous (or, as is often the case, the sample density or special nuclear material self-shielding requires the use of relatively high-energy neutrons).

In all these cases, gamma-ray backgrounds, self-shielding, or matrix effects can make gamma-ray assays impractical. Materials ranging from highly radioactive spent-fuel assemblies to low-level waste drums have been assayed with shufflers, as have leached hulls, various process materials, scrap, and waste (LA-12105).

Calorimetry

Calorimetry is the quantitative, nondestructive measurement of heat. It measures the transfer of energy from one system to another caused by temperature differences. Radiometric calorimeters measure the power associated with alpha, beta, or gamma decay of radioactive materials, and the power can be related to the mass of the material. Radiometric calorimeters operate on the principle that almost all of the energy from radioactive decay of materials placed in the sample chamber is absorbed in the form of heat within the calorimeter. The radioactive decay of all uranium and plutonium isotopes generates heat, but only the plutonium isotopes, because of their shorter half-lives and thus higher specific activities, generate heat at a power level that can be measured accurately. The dominant decay mode of plutonium isotopes is alpha decay. Since alpha particles travel only a very short distance before interacting with matter, virtually all of the energy released by alpha decay remains within the sample as heat.

Important features and advantages of the calorimetric assay of plutonium are:

- The assay is independent of sample geometry, special nuclear material distribution in the sample, and matrix material composition.

- Heat standards are directly traceable to National Institute of Standards and Technology reference materials; representative plutonium standards are not needed.

- The assay is comparable to chemical assay in precision and accuracy if the isotopic composition is well characterized.

- The assay is applicable to a wide range of material forms; including metals, alloys, oxides, fluorides, mixed oxides, waste, and scrap. Plutonium can be measured in the presence of uranium.

This type of assay is not without its drawbacks. The major consideration in selecting this method is the time necessary to complete an assay. There are many factors that influence the assay time. Assay times may range from one hour for small samples with low accuracy and precision needs to 16 hours if high accuracy and precision are needed and the samples are large.

Measurement Capabilities in the DOE Complex

NDA measurement of high enriched uranium (HEU) typically uses a californium shuffler or AWCC. Active well neutron multiplicity techniques are currently being field tested and may be advantageous for future applications (notably international inspections of HEU metal at United States facilities). Holdup is measured using a scintillation detector, such as NaI (Figure D-5), based on assumptions about material distribution in the equipment or area being measured.

NDA measurement methods for plutonium include calorimetry with gamma isotopic analysis, neutron coincidence counting with gamma isotopic analysis, neutron multiplicity counting with gamma isotopic analysis, or a segmented gamma scan. Holdup is typically measured with a scintillation detector and extensive calculations based on the observed count rates and assumptions about material and isotopic distributions in the equipment or area being measured.

Holdup has been measured using both gamma and neutron measurement systems. In some facilities, it has been estimated or not addressed and is assumed to be zero. There are a few facilities that use a combination of these approaches. Currently, the 186 keV gamma ray is used to measure HEU holdup. The 414 keV gamma ray region is used for plutonium holdup measurements. Neutron measurements have been used for plutonium and large deposits of HEU. Gamma ray measurements are sensitive to thickness of deposit and shielding by process equipment, while the measurement of neutrons is affected by the production or absorption of neutrons by other elements.

Original and vendor-supplied equipment in use at many DOE processing facilities have been in service for many years. Although the technology was the best available at the time of purchase, much of the equipment currently in use does not reflect "state-of-the-art" measurement capability. Historically, NDA equipment was developed to meet an existing need. The equipment was designed by DOE national laboratories and evaluated for specific processing applications or material forms. Subsequently, designs were improved and the technologies were transferred to equipment vendors and became commercially available.

Comparison of DOE and IAEA Approaches

The study compared the IAEA's approach to NDA to the approach used in the DOE. The IAEA has standardized measurement methods

and data analysis software. The IAEA equipment is similar to the DOE equipment, although it has wider applicability because of the development of specialized detectors (such as fuel bundle collars). The IAEA does not use calorimetry, and the AWCC has had only minimal use in IAEA field measurements because of the limited quantities of metal outside the United States and the former Soviet Union. The AWCC is currently being field tested in the United States, as well as a version of the AWCC using multiplicity counting.

Although NDA is used both nationally and internationally, the requirements for obtaining accountability values are different. Nationally, DOE orders require that each facility have an accountability measurement method for all nuclear material on inventory, including special nuclear material in receipts. When processing operations are suspended, the capability to obtain samples and perform destructive analysis is limited, and NDA becomes the preferred method. When the requirement, as is the case for the IAEA, is to independently verify the facility's nuclear material inventory values, the advantage of NDA to compare items rapidly and accurately dictates the need for NDA. When NDA is supplemented by the destructive analysis of a sample from a group of items, the accuracy, precision, and traceability of the destructive analysis measurement can be extended to all items, thereby reducing the uncertainty of the independent determination. This approach is proven and is preferable for international inspections.

Conditions for Use of NDA Techniques

In order to have an NDA technique available for use, a site must purchase the necessary equipment and establish environmental conditions for its operation. Environmental conditions include control of temperature, humidity, and contamination. Criticality, health, and safety reviews must be conducted and the equipment operation approved for use. These reviews are costly, time-consuming, and impact staff that are essential to current consolidation activities.

Standards must be developed to calibrate the instruments. Standards development and calibration of NDA systems are the most difficult and often the most expensive component of qualifying an NDA measurement method. The special nuclear material content of the standards must be established in a manner that is traceable to the national measurement base. The traceability is generally accomplished by destructive analytical techniques which may not be available on site. The special nuclear material content must be representative of the materials to be measured, and the matrix of the standard must duplicate the unknowns in those attributes that affect the particular NDA technique.

All of the activities for calibrating the instruments, performing the measurements, and handling the material being measured require extensive procedures development. DOE orders require that personnel be trained and qualified to perform the activities detailed in the procedures.

Ongoing costs to maintain NDA measurement systems include requalifying methods, reviewing and updating procedures, and retraining measurement personnel. These costs are significant over the life of the equipment and must be considered in the initial selection of measurement methods.

NDA Software

FRAM, MGA, and TRIFID are examples of different software codes currently in use in the DOE complex that are used to quantify plutonium gamma isotopic ratios. Not all software source code listings are available to DOE facilities. For example, data analysis software developed at Los Alamos is available on request to commercial vendors, but only the compiled form of the code is available to DOE facilities until the software is fully documented and evaluated. Facilities must maintain the software for their systems, and modifications to the national laboratory-developed software have occurred. For example, the Rocky Flats Plant is developing software to address site-specific needs.

Software differences arising from the different generations of equipment, the different sources of equipment, and the variations in upgrades have contributed to inventory differences and shipper-receiver differences. For example, there was one instance when two gamma isotopic codes resulted in a significant shipper-receiver difference because each code used a different methodology for determining net peak area. The measurement control programs at both facilities indicated that the systems were in control. Artificial differences in measured values caused unnecessary investigations. During consolidation and decontamination and decommissioning activities, the occurrence of similar anomalies is expected to increase.

The effect of software on special nuclear material measured values can be controlled through proper calibration techniques when standards are representative of the materials being measured. Since development of standards for all material forms is not cost effective, the difference between the standard and the material is addressed in the software. When standards are not representative of the materials, the mathematical expressions in the software used to accommodate variations between the standard and the item being measured can introduce an error into the measurement result. Calculation of attenuation and special nuclear material self-attenuation are examples of gamma-ray measurement effects modeled using mathematical expressions. Software calculations are also made for gamma-ray isotopic measurements used in neutron assay and calorimetry measurements. The difference in software can create inconsistencies between facility measurements and within facilities that have multiple measurement systems. In addition, when codes are changed, facilities do not always remeasure containers or recalculate previously measured values.

An effective measurement control program will assist in measuring the effect of software differences. However, without software controls, measurement differences between measurement systems can occur despite an apparently effective measurement control program.

Containers

All special nuclear material must be put into containers for movement and storage. The type and size of these containers vary from site to site. These variations have limited the ability of the complex to standardize NDA instrumentation and have necessitated the design and fabrication of unique systems. The only special nuclear material container that is somewhat standardized is the 55-gallon (208-liter) drum. This drum was standardized because of the demand for commercially available waste containers. The use of this drum facilitated the commercialization of the SGS. Currently, most facilities have an SGS, and many facilities have more than one system. However, other NDA systems have been developed based on site-specific container criteria.

The NDA of special nuclear material is influenced by the geometry of the special nuclear material being measured and by the materials between the detectors and the special nuclear material. Detectors must be of sufficient size to monitor the entire container, and they must be configured so that their response to the special nuclear material is constant or nearly constant over the entire volume of the container. Thus, with the variety of containers in the DOE complex, the measurement equipment must be designed for each container type for optimum measurement results.

As an example, the equilibrium times required by calorimetry measurements are influenced by the closeness of the fit between the measuring chamber and the container of special nuclear material. To obtain optimum measurement results for specific containers, site-specific calorimeters have been developed. In one instance, a facility requested that a calorimeter be designed to accommodate one-gallon paint cans. The system was fabricated and delivered, but when initial measurements were attempted, it was discovered that the calorimeter had been designed for cans without handles, while facility cans had handles. The variation in container diameter was approximately one-half inch, and the containers would not fit in the measuring chamber. Since the cost and radiation exposure resulting from re-packaging was unacceptable, the facility was unable to perform accountability measurements until a new NDA system was available.

Additionally, waste boxes, cans for oxide, and cans for metal have also required the fabrication of site-specific NDA systems such as californium shufflers, active well coincidence counters, and waste box counters. In general, these site-specific NDA systems differ only in their design to accommodate a specific container size, even though the special nuclear material contents are similar in those attributes that impact NDA measurements.

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APPENDIX E
MEASUREMENT UNCERTAINTIES AND DIFFERENCES

This appendix provides general background information about measurement uncertainties, uncertainties in holdup measurements, and measurement differences. This information may help persons who are not familiar with some of the technical aspects of measurements to better understand some of issues raised in the main report.

Measurement Uncertainty

Uncertainty is a concept used to describe the inability of a measurement process to measure exactly the true value sought (ANSI N15.5-1982, *Statistical Terminology and Notation for Nuclear Materials Management)*. The uncertainty consists of measurement error due to the limitations of the measurement process. "Error" does not mean poor work by the technician but is used to describe the deviation from the true value. Uncertainty is a result of attributes or factors causing the measured value to differ from the true value. These attributes may occur from the measuring device, the standards used, techniques of the technician, environmental factors, or other factors yet to be determined. The magnitude of the uncertainty may be represented by one, two, or three standard deviations.

Sources of error, when controlled, help reduce the uncertainty for the unknowns. The following list of sources of uncertainty is taken from ***Statistical Methods for Nuclear Material Management***, W. Michael Bowen and Carl A. Bennett, 1988, p. 671. They include:

- Material Sampling: The value of the concentration obtained depends upon the particular sample of material chosen.
- Statistical Sampling: The measurement result for the characteristic of interest which will be applied to the whole population is affected by the sample of items selected.
- Analytic Technique: The measurement obtained from a measurement process may depend upon the analytic technique or procedure used to measure the material.
- Instrument: As already discussed, the instrumentation used to obtain a measurement may affect the result.
- Analyst or Operator: The people operating a measurement process may affect resulting measurements.
- Calibration: Using a calibration equation or procedure to indirectly measure a quantity of interest in a measurement process affects the measurement obtained.
- Environmental conditions: The environment surrounding a measurement process may affect measurements.

Attempts made to find the true value of a measurement must be related to the accuracy and precision of the measuring device as well as to the material characteristics. Accuracy is how well the system can measure a known value such as a standard. Good accuracy alone will not guarantee a small uncertainty with the measuring device. Precision is a measure of the system's ability to repeat the measured value.

There are factors that cause a measurement process to generate a value different from the standard value. The factors are not peculiar to the measuring device alone. They come from all parts of the measurement process. One important part of the measurement process is a standard. A perfect standard cannot be created. But standards can be created that are very near perfect for some applications. However, even these near perfect standards will have an uncertainty. The uncertainty information is usually included with the standard certification that comes from the New Brunswick Laboratory. The uncertainty describes the inability of the certification to define the true value of the standard. The uncertainty of the standard may not be large enough for the measurement process to detect during actual application. However, the standard uncertainty must always be considered when determinations are made for the uncertainty of a measurement process.

Sometimes standards cannot be purchased for a measurement process. This is often the case with standards for nondestructive assay (NDA) equipment. Thus, standards are often prepared by a facility. The material used in the standard preparation must be characterized and an uncertainty established for the value of the standard material. A destructive analysis method may be used and the method should have data to determine the uncertainty. The uncertainty should include information from the sample preparation. This should include factors such as balance uncertainty and glassware uncertainty used for the sample preparation. Once the destructive analysis establishes a value for the material used to prepare the standard, the material will be configured in the container to be used with the NDA equipment. This configuration should represent the typical container that will be measured.

The value of the standard will be established from the destructive analysis and sample preparation data. A statistical combination of the uncertainties that were present during the standard preparation will establish a value for the standard uncertainty. This value once established should be the uncertainty used for the life of the standard.

The information for the standard must be determined to help quantify the "inability to measure the true value" for unknowns. The uncertainty of the standard will be used to establish the uncertainty for unknowns whose values are determined with the measurement process. The uncertainty for the unknowns can be determined from examining the standards data generated from the measurement process. Measuring some unknowns twice, called replicating, would help provide additional information to establish a value for the uncertainty of the unknowns.

While the uncertainty of the standard is established for the life of the standard, the uncertainty for our measurement process can possibly be reduced as data are collected and evaluated for specific measurement methods. Examining the items from the above list will provide areas where the uncertainty might be reduced. Uncertainty cannot be completely eliminated since it is not possible to make "perfect measurements" or "perfect standards." However, in the new era of "openness" combined with the new mission for most parts of the complex, it becomes increasingly important that uncertainty values are well documented and defensible since the possibility for outside examination may exist.

A small error in the inventory value for an item is not important from a safeguards perspective since small errors cannot readily be exploited to conceal the diversion of significant quantities of special nuclear material. However, larger errors are a significant concern. Large errors can present an opportunity to conceal a diversion of material, and can adversely affect worker safety. Another concern is the accumulation of small errors in a large number of items, resulting in a large total error. Because of the large number of items involved, it would be difficult for a single insider to conceal diversion of a significant quantity of material. However, an accumulation of small errors can make it difficult to assure that no diversion has occurred.

Uncertainty in Holdup Measurements

When holdup measurements are made, there is a high uncertainty in the results of those measurements. The uncertainty arises from the measurement system and the assumptions made when relating count rates to grams of special nuclear material. The assumptions concern the distribution of the material, the physical and chemical forms of the material, the depths of the material deposit, and the process containment materials. These assumptions affect the translation of the instrument response to grams of special nuclear material.

Other contributors to the uncertainty include personnel, standards, and a lack of validation of inventory values. The measurement of holdup is manpower intensive, often requiring the cooperative efforts of two or more individuals. Shielding must be used to reduce background radiation and the measurement requires positioning the detector to isolate the area to be measured. These activities are often physically demanding and potentially hazardous. The limited ability to reproduce these measurements introduces a large random error in the measured value. Because of the high degree of uncertainty associated with holdup measurements and estimates, criticality safety programs often double holdup inventory values to ensure a substantial margin of safety.

It is impossible and impractical to fabricate standards that reflect the physical and chemical forms of the special nuclear material in holdup locations. As a result, holdup measurements have an inherent bias and a systematic error variance. Because of the difficulty and expense in determining the bias and systematic error variance, these errors are estimated. A generalized geometry approach assuming point, line, and area sources addresses some of these errors, but the measurement uncertainty is large. The large number of measurements needed to quantify all holdup locations contributes to the large uncertainty. Unknown process containers and special nuclear material signal attenuation are also sources of error from estimation.

Measurement Differences

Measurement differences will exist because of different measurement devices, standards, calibration methods, and user techniques. These differences result in the uncertainty which is described as "the inability of a measurement process to measure exactly the true value sought" (ANSI N15.5-1982, *Statistical Terminology and Notation for Nuclear Materials Management*). The differences that occur from the "true value" will be both positive and negative differences, unless the uncertainty is dominated by a bias in one direction. The precision and accuracy indicate the inability of a system to have complete repeatability. Accuracy is how well the system can measure a known value such as a standard. Precision is a measure of the system's ability to repeat the measured value.

The accuracy and precision must be controlled if the measurement system is to provide useable data. The combination of good precision and good accuracy will provide a measurement system which produces good quality data. It is impossible to have perfect accuracy and perfect precision; therefore, differences will exist even if the same item is measured on the same system.

Measurement differences in some instances may not be significant enough to cause concern. Using exactly the same measurement system does not guarantee receiving exactly the same value due to the inherent characteristics of a measuring system. These differences begin with the precision and accuracy of a system. While the repeatability may not always be exact, the difference in the measurements should be very small.

Good measurement control exercised over the precision and accuracy of the measurement system minimizes the observed differences. The actual significance may need to be evaluated statistically. The significance may be determined by established statistical tests, or previously determined criteria listed in operating procedures or mutually agreed upon actions defined in a shipper-receiver agreement. All established criteria need a statistical evaluation as the basis for the decision. The statistical evaluation involves taking the uncertainty from all components of the measurement system to establish an overall uncertainty for measurements which are made on the system.

Shipper/receiver difference evaluations depend on the shipper/receiver agreements made prior to the shipment. In many instances a statistical evaluation is made. The agreement may require a statistical combination of the uncertainty for both the shipper's and receiver's measurement systems. If the difference is within the bounds the uncertainty makes around the receiver's value, the difference is accepted as a normal occurrence and both the shipper and receiver use their own values.

There will be occasions when the difference will exceed the band of uncertainty around the measurement systems. By the very nature of the definition with the uncertainty being an expression for two standard deviations it should be understood that differences exceeding the band are expected to occur five percent of the time. On those occasions the decision must be made to strictly accept the statistical conclusion or evaluate in real terms the impact of accepting the actual differences.

There will be occasions where it is virtually impossible to include all the measurement system's uncertainty in the final uncertainty expression. This emphasizes the need for the option of evaluating the real difference for actual impact. Even though the difference is statistically significant the impact of the actual difference may be minimal enough to accept the difference.

Measurement differences will always be a part of operations. Guidelines must be established to assist in the decision making. Without the statistical analysis or guidelines, efforts would be spent interpreting measurement differences that are a result of the capability of the measurement system. In addition to evaluation of measurement uncertainty, an investigative process must be established that documents the review and provides a definitive disposition of the measurement.

APPENDIX F
OPTIONS FOR MEASURING MATERIALS

This study has identified five basic options for enhancing fissile inventory assurance in the Department of Energy (DOE) complex:

Option 1: Status Quo
Option 2: Measure Material
Option 3: Ship Materials
Option 4: Ship Instrumentation
Option 5: Convert Material.

Each of these five options is evaluated in general terms below. The criteria used for evaluating the options were:

- **Safeguards Effectiveness**. Does the option provide reasonable control and accountability of special nuclear material?

- **Timeliness**. Does the option provide the potential for the timely reduction of unmeasured inventory?

- **Cost**. Is the cost of implementing the option reasonable for the return on investment?

- **Health and Safety**. Does the implementation of the option pose any significant problems to the general well-being of plant workers and the public?

Facilities should consider conducting a similar evaluation for specific material types using the same five options and evaluation criteria. The results of such a review can be recorded on tables such as Table F-1, which is provided at the end of this appendix. A hypothetical example of a completed table is also included in Table F-2.

Option 1: Status Quo

The status of special nuclear material inventories varies around the DOE complex. Some facilities have measured all of their material. Some facilities have a significant number of items with estimated values or shipper's values that have not been verified. Some scrap and waste materials have been generated that, by their nature, are "difficult-to-measure." Holdup of special nuclear material is either measured, estimated, or no value assigned and not included in the physical inventory.

This option offers the least safeguards value for the control of special nuclear material. The confidence with which the inventory statements can be made decreases as the quantity of unmeasured material increases. The status quo does not provide the means for timely reduction of unmeasured inventory. If the special nuclear material is in item form, is amenable to measurement using available methods, and is selected during the physical inventory verification, facilities will measure the item using an approved verification method and the result will be entered into the accounting records. However, physical inventory verification sample sizes are small compared to the inventory population which means that there is very little opportunity for selection of unmeasured items.

Since there are no additional operational changes associated with the status quo option, there are no extra costs. Similarly, there are no added risks associated with additional handling of materials that may occur with other options. However, maintaining unknown quantities on inventory can have risks associated with health, safety, and environment concerns and the undetected theft or diversion of special nuclear material. It becomes more difficult to say that material has not been removed for the purposes of fabricating a nuclear weapon or committing radiological sabotage. Although this option has the least impact on facility operations, it does not provide an acceptable solution to the problem of unmeasured material in the DOE complex.

Option 2: Measure Material

This option assumes that measurement capability exists at the facility to measure the material, but that the measurements may not be of the highest quality or the inventory values are based on estimates, batch values, or stream averages. While the values for the material may have values based on accurate processing information, the confidence that material has not been diverted is low since each container does not have a measured value. Therefore, this option provides for a measured value for all previously unmeasured containers using available systems. If previous values are estimated, the measured values are entered into the accountability records.

The safeguards effectiveness is greatly enhanced when all of the material is measured. Even quantitative measurements of low quality provide assurance that the material is as stated in the accountability records. While the best value may be obtained from a calorimetry measurement, a neutron or gamma measurement should provide adequate safeguards information in a more timely manner.

There are some tradeoffs between timely measurements and health and safety. A program to measure all materials would provide the most timely solution to the unmeasured material issue. However, that approach may be prohibitive from the "as-low-as-reasonably-achievable" (ALARA) approach to radiation exposure when dealing with plutonium. An alternative approach to measuring all of the material in one campaign is to stratify the physical inventory into items with measurements and those without measurements. At the time of the physical inventory, a statistical sample of both populations, more heavily weighted towards the unmeasured items, is used to select items for measurement using methods and instrumentation that provide the quickest quantitative value. This approach would delay obtaining measurements for each item, but may be preferable for the health and safety of workers. As the population of unmeasured items decreases, the statistical sample is modified so that the time to complete all measurements is reduced. Both measured and unmeasured items need to be selected at the time of inventory to assure that each item has a possibility of being selected.

Option 3: Ship Materials

This option assumes that the capability to measure the materials exists at some facility within the DOE complex. Essentially, the special nuclear material is transferred at the "book value" to a facility with the measurement capability and the resulting measured value is assigned to the transfer. It is recognized that difficulties exist that focus on certification of shipping containers and compliance with Department of Transportation regulations. These obstacles must be overcome prior to the implementation of this option.

Implementing this option assumes that the shipper, receiver, and their respective DOE operations offices have a shipper-receiver agreement in place allowing the transfer to be made at "book value" and the measurement results are acceptable to all. Agreements of this type have been made in the past; e.g., Portsmouth weights of UF_6 in 10-ton cylinders have been accepted by their clients because of their ability to accurately weigh that large quantity of uranium. The material may either be stored at the receiver's facility or returned to the shipper.

As long as controls are maintained throughout the transfer and measurement steps, this option assures that quality measurements are made and the values accurately reflect the inventory items. There is an increased safeguards risk associated with the movement of materials, but that is offset by the characterization of the material that may have been carried on the accountability books as estimated or "by-difference" values which decrease the special nuclear material inventory assurance.

When the decisions have been made to transfer materials for measurement and possibly storage, this option has the capability to reduce the unmeasured inventory in a timely manner. Some material will need to be packaged in suitable containers for shipping. Many materials can be shipped in their current form, but some may require a pre-processing step to bring the material into a stable form for shipping. If processing is necessary, considerable time may be required to obtain approvals and prepare the facility for these operations. If pre-processing is not viable based on facility operating conditions and other controls in place, then this option may not be the optimum choice.

This option may also be costly in preparing the materials for transport. If the materials are in a form that can be readily packaged into shipping containers, the costs for measuring the materials will primarily be associated with the transportation. Commercial carriers can be used for Category III shipments and will be less costly than Category I and II shipments made by the Safe Secure Trailer (SST).

Transportation of special nuclear material does involve certain risks. The packaging and handling of the materials at the shipper and receiver involves a certain risk to the workers in the form of radiation exposure for plutonium items and the potential for contamination incidents. Shipments between DOE sites have been historically safe, but there are risks to the public of accidental releases, theft and sabotage.

This option would meet safeguards needs for assuring that the special nuclear material inventory values are correctly stated if the measurement capability exists at one DOE site. This may be the best option if the decision is made to consolidate materials of one type in one location for long-term storage.

Option 4: Ship Instrumentation

This option assumes that measurement instruments are not available at the facility with unmeasured special nuclear material, but that they are available elsewhere. The instruments (and personnel if necessary) are shipped to the facility, the measurements are made, and the instruments returned or shipped to another facility for similar measurements. For this option to be cost-effective, the instrumentation must be of a size to make transportation feasible, such as neutron well coincidence counter, segmented gamma scanner, and portable calorimeter. This option is not intended to address the permanent transfer of equipment addressed previously although the implementation issues are similar.

The advantage of this option is that the best instrumentation to measure a particular material type and form is brought to the material that needs to be measured. The special nuclear material remains within the control and accountability system of the facility in which it resides. Special arrangements will need to be made for qualifying the measurement method and personnel according to facility requirements. If instrumentation and measurement personnel were qualified under another facility's measurement control program, agreements between facilities and DOE operations offices would be needed for accepting the method. However, given the fact that the inventory assurance is increased by these measurements, those agreements should be obtainable.

The timeliness of implementing this option depends on the availability of instruments at other sites, time required to obtain necessary approvals, time required to install equipment in an acceptable and approved location, and conduct testing and qualification activities. However, once approvals have been obtained, the actual time for movement and setup of the equipment should be relatively short.

This option is cost effective for the DOE since purchasing additional equipment is not necessary. If facilities were operating in full production modes, then purchase is the best option. However, most of the facilities are in standby or cleanup modes. Sharing equipment resources throughout the DOE complex can result in substantial savings when their use is needed for short-term operations.

Since the equipment is moving to a site location and not the material, the risks associated with the measurement operation are no different than measurements previously made at the facility. This assumes that the equipment is positioned in the facility in an approved location for handling special nuclear material.

This option would meet safeguards needs for assuring that the special nuclear material inventory values are correctly stated if the measurement equipment is available at another DOE site. This may be the best option if the decision is made to store special nuclear materials in their current locations around the DOE complex.

Option 5: Convert Material

If the special nuclear material is not measurable in its existing form, then this option addresses the measurement issue through processing the material to a form that is measurable. This option is limited to processing methods and methods that have demonstrated ability to recover special nuclear material.

Implementing this option has significant safeguards concerns that must be addressed. Since the items undergoing processing do not have a measured value, there is probably a large uncertainty in the knowledge of the special nuclear material content of the items. This makes this processing operation more vulnerable to undetected diversion. In order to provide effective safeguards throughout the process, controls must be in place to preclude losses of material and monitor the input and output.

Given the state of processing operations around the DOE complex, implementing this option may require extensive reviews and approvals. This option may be expensive to implement, especially if new recovery processes have to be developed or existing processes must be modified. However, further development of plutonium recovery methods should be encouraged to place the plutonium in a stable form that can be stored for the long term.

Processing special nuclear material to a form suitable for measurements does not require any significant health and safety risks that are not already realized under normal production operations. A concern may be that the risks of processing are greater than leaving the material in its current form. However, unstable material is currently on inventory that poses significantly greater risks if it is maintained in its current state. Processing must occur before the material can be prepared for long-term storage. If the material is already in a stable form, processing is probably not a viable solution to achieving measured values. Methods and instrumentation are available that can provide a measurement for the purposes of special nuclear materials accounting.

Table F-1. Analysis of Options for Measuring Material

Material Type:
Measurement Options:

OPTION	EVALUATION CRITERIA				
	Safeguards Effectiveness	Timeliness	Cost	Health and Safety	Overall Assessment
1. Status Quo					
2. Measure Material					
3. Ship Materials					
4. Ship Instrumentation					
5. Convert Material					

Decision:

Table F-2. Hypothetical Example of Analysis of Options

Material Type: Unstable oxides in glovebox storage
Measurement Options: Semiquantitative: gamma
Quantitative: calorimetry/isotopic (requires processing)

OPTION	EVALUATION CRITERIA				
	Safeguards Effectiveness	Timeliness	Cost	Health and Safety	Overall Assessment
1. Status Quo	diversion risk	NA	no increment	significant concern	involves risks and is untenable situation
2. Measure Material	semiquantitative measurement would enhance safeguards but not meet long-term objectives	timely	low	small exposure from measurement	only short-term option available, but only a stopgap
3. Ship Materials					not possible until converted to stable form
4. Ship Instrumentation					not necessary
5. Convert Material	allows accurate measurement	cannot be conducted until processing operations are allowed to be conducted	medium	small exposure from measurement, eliminates significant ES&H concern	preferred option for long term

Decision: conduct semiquantitative measurement (Option 2) as interim measure, conduct better measurement when operations restart (Option 5)

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APPENDIX G
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